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RIVER BASIN VALIDATION OF THE WATER QUALITY ASSESSMENT METHODOLOGY FOR SCREENING NONDESIGNATED 208 AREAS

Volume I: Nonpoint Source Load Estimation

by

Michael J. Davis, Michael K. Snyder, and John W. Nebgen

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

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Project Officer

Robert B. Ambrose
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30613

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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In this volume, the successful application of the MRI-developed nonpoint loading procedures under field conditions in five river basins is described and the compatibility of these procedures with the 208 screening methodology is demonstrated. Volume II describes the application of the Tetra Tech-developed nondesignated 208 screening methodology to the same river basins. The basins in which the assessment techniques were used were the Sandusky River in Ohio and four Chesapeake Bay Basins (Patuxent, Chester, Occoquan, and Ware Rivers).

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools to help pollution control officials achieve water quality goals through watershed management.

In earlier work sponsored by EPA, water quality assessment techniques were developed for characterizing pollution problems in nondesignated 208 areas and loading functions were developed for estimating quantities of different pollutants entering receiving water bodies from nonpoint sources. It appeared that these two tools used in concert might provide an adequate set of methods for screening nondesignated 208 areas by simple hand calculation procedures. This report describes the application of both methods to the identification of water quality problem areas in several river basins in the United States.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

In earlier work under the sponsorship of EPA, loading functions were developed by Midwest Research Institute (MRI) for estimating the quantities of different diffuse loads entering receiving water bodies from nonpoint sources and a screening methodology was produced by Tetra Tech, Inc., for assessing water quality problems in areas not covered under Section 208 of the Federal Water Pollution Control Act Amendments of 1972. The two methods had never been applied together under realistic conditions, however, to demonstrate how the combined techniques might be used for identification of water quality problems in U.S. rivers.

In this volume, the successful application of the MRI-developed nonpoint loading procedures under field conditions in five river basins is described and the compatibility of these procedures with the 208 screening methodology is demonstrated. Volume II describes the application of the Tetra Tech-developed nondesignated 208 screening methodology to the same river basins. The basins in which the assessment techniques were used were the Sandusky River in Ohio and four Chesapeake Bay Basins (Patuxent, Chester, Occoquan, and Ware Rivers).

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CONTENTS

Figures ix
Tables. x
1. Introduction. 1
    1.1 Background 1
    1.2 Purpose and Scope. 2
    1.3 Format and Organization. 3
2. Demonstration of Methods. 6
    2.1 Demonstration Example: The Sandusky River Basin 6
        2.1.1 Character of the Basin. 6
        2.1.2 Nonpoint Load Estimation Methodology - An Overview. 9
        2.1.3 Rural Nonpoint Sources. 12
            2.1.3.1 Parameter Evaluation 12
                2.1.3.1.1 Rainfall Factor (R) 13
                2.1.3.1.2 Soil Erodibility Factor (K) . 15
                2.1.3.1.3 Slope Factors (L and S) . . . 16
                2.1.3.1.4 Cover Factor (C). 17
                2.1.3.1.5 Support Practice Factor (P) . 23
                2.1.3.1.6 Land Use Within the Sandusky Basin 24
                2.1.3.1.7 Nutrients 29
                    2.1.3.1.7.1 Determination of Enrichment Ratio. 30
                    2.1.3.1.7.2 Nutrient Concentration. . . . 30
                    2.1.3.1.7.3 Rainfall Nitrogen . . . 32
                2.1.3.1.8 Sediment Delivery Ratio . . . 33
            2.1.3.2 Load Determination 34

[illegible]

2.1.4 Urban Nonpoint Sources. 37

  2.1.4.1 Combined Sewer Overflows--Methodology. . 37

  2.1.4.2 Character of the Urban Areas of the Sandusky River Basin 40

  2.1.4.3 Load Estimation. 41

2.1.5 Nonpoint Source Impacts on Water Quality. 48

2.2 Demonstration Example: The Chester River Basin. 48

2.2.1 Character of the Basin. 48

2.2.2 Nonpoint Load Estimation Methodology - An Overview. 51

2.2.3 Rural Nonpoint Sources. 51

  2.2.3.1 Parameter Evaluation 51

    2.2.3.1.1 Rainfall Factor 51

    2.2.3.1.2 Soil Erodibility Factor (K) . 53

    2.2.3.1.3 Slope Factors (L and S) . . . 53

    2.2.3.1.4 Cover Factor (C). 54

    2.2.3.1.5 Support Practice Factor (P) . 57

    2.2.3.1.6 Land Use Within the Chester River Basin 57

    2.2.3.1.7 Nutrients 58

    2.2.3.1.8 Sediment Delivery Ratio . . . 59

  2.2.3.2 Load Determination 59

2.2.4 Nonpoint Source Impacts on Water Quality. 60

2.3 Demonstration Example: Patuxent River Basin 60

2.3.1 Character of the Basin. 60

2.3.2 Nonpoint Load Estimation Methodology--An Overview. 61

2.3.3 Rural Nonpoint Sources. 63

  2.3.3.1 Parameter Evaluation 63

    2.3.3.1.1 Rainfall Factor (R) 63

    2.3.3.1.2 Soil Erodibility Factor (K) . 63

    2.3.3.1.3 Slope Factors (L and S) . . . 66

    2.3.3.1.4 Over Factor (C) 66

    2.3.3.1.5 Support Practice Factor (P) . 68

2.3.3.1.6 Land Use Within the Patuxent River Basin 68
2.3.3.1.7 Nutrients 71
2.3.3.1.8 Sediment Delivery Ratio . . . 72
2.3.3.2 Load Determination 72
2.3.4 Urban Nonpoint Sources. 73
2.3.5 Nonpoint Source Impacts on Water Quality. 73
2.4 Demonstration Example: Ware River Basin 74
2.4.1 Character of the Basin. 74
2.4.2 Nonpoint Load Estimation Methodology--An Overview. 74
2.4.3 Rural Nonpoint Sources. 76
2.4.3.1 Parameter Evaluation 76
2.4.3.1.1 Rainfall Factor (R) 76
2.4.3.1.2 Soil Erodibility Factor (K) . 77
2.4.3.1.3 Slope Factors (L and S) . . . 77
2.4.3.1.4 Cover Factor (C). 77
2.4.3.1.5 Support Practice Factor (P) . 79
2.4.3.1.6 Land Use Within the Ware River Basin 79
2.4.3.1.7 Nutrients 79
2.4.3.1.8 Sediment Delivery Ratio . . . 79
2.4.3.2 Load Determination 79
2.4.4 Nonpoint Source Impacts on Water Quality. 80
2.5 Demonstration Example: Occoquan River Basin 80
2.5.1 Character of the Basin. 80
2.5.2 Nonpoint Source Load Estimation Methodology--An Overview. 81
2.5.3 Rural Nonpoint Sources. 83
2.5.3.1 Parameter Evaluation 83
2.5.3.1.1 Rainfall Factor (R) 83
2.5.3.1.2 Soil Erodibility Factor (K) . 84
2.5.3.1.3 Slope Factors (L and S) . . . 84
2.5.3.1.4 Cover Factor (C). 84
2.5.3.1.5 Support Practice Factors (P). 86

2.5.3.1.6 Land Use With the Occoquan River Basin 87
2.5.3.1.7 Nutrients 87
2.5.3.1.8 Sediment Delivery Ratio . . . 88
2.5.3.2 Load Determination 88
2.5.4 Urban Nonpoint Sources. 88
2.5.5 Nonpoint Source Impacts on Water Quality. 89
3. Determination of Nutrient Fluxes in Streams, With Case Studies of the Potomac and Susquehanna Rivers 90
3.1 Introduction 90
3.2 Methodology. 90
3.3 Case Study: Potomac River Basin 95
3.4 Case Study: Susquehanna River Basin 105
3.5 Discussion 114
4. Discussion and Conclusions. 117
4.1 Data Availability. 117
4.2 Value of Parameter Refinement. 118
4.3 Sensitivity Analysis 119
4.4 Level of Effort Required in an Application 121
4.5 Verification of the Load Estimation Procedures 121
4.6 Future Applications. 121
4.7 Use of the Load Estimation Methodology in Specialized Applications 122
4.8 Attainment of the Goals of the Study 122
4.9 Impact of Methodological Shortcomings on an Assessment . 123
References. 125
Appendix I. P Factors, Slopes, and Slope Lengths Used in Chapter 2 . 128 128
Appendix II. Soil and Nutrient Loss Calculations for Chapter 3. . . . 143 143
Appendix III. English to Metric Conversions for Volume I 145 145

FIGURES

Number Page

2-1 Sandusky River Basin. 7
2-2 Chester River Basin and Subbasins 50
2-3 Patuxent River Basin and Subbasins. 62
2-4 Ware River Basin and Subbasins. 75
2-5 Occoquan River Basin and Subbasins. 82
3-1 Potomac River Basin 97
3-2 Susquehanna River Basin 106

TABLES

Number Page

2-1 Sandusky River Subbasins. 8
2-2 Evaluation of EI_{30} for the Sandusky Basin 14
2-3 Average K Factor Values by Subbasin for the Sandusky. 16
2-4 Agricultural Data for Counties in the Sandusky Basin in 1975. 17
2-5 Estimated Areas of Principal Crop Rotations by County in the Sandusky River Basin for 1975 19
2-6 Determination of Cover Factor for Corn After Soybeans by Crop Stage 20
2-7 Cover Factors for Corn for the Sandusky Basin 21
2-8 Cover Factors for Soybeans for the Sandusky Basin 21
2-9 Cover Factors for Grain for the Sandusky Basin. 22
2-10 Cover Factors by Event and by Crop for the Sandusky Basin . . 23
2-11 Land Capability Classes and Land Uses 25
2-12 Land Uses in the Sandusky Basin 28
2-13 Soil Nutrient Concentrations in the Sandusky River Basin. . . 31
2-14 Resolution Associated with Important Parameters in Rural Nonpoint Analysis 34
2-15 Estimated Stream Loading Rates for the Average Sandusky Event, Sediment Delivery Ration = 0.1 36
2-16 Estimation of Loads Associated with Sanitary Sewage in Dry Weather Flow. 38
2-17 Sandusky River Basin Urban Areas. 41
2-18 Street Loading Rates for Bucyrus. 42
2-19 Estimated Annual Loads from Combined Sewer Overflows. 42
2-20 Estimated Annual Loads in Stormwater Runoff, Not in CSOs. . . 43
2-21 Estimated Total Annual Urban Loads. 43
2-22 Comparison of Load Estimates for Bucyrus. 45
2-23 Average Unused Capacity of Plants During Dry Flow Period. . . 45
2-24 Components of Combined Sewer Overflow Loads for Bucyrus . . . 46
2-25 Comparison of CSO Loads for Bucyrus 48

TABLES (Cont'd)

Number Page

2-26 Chester River Subbasins 49
2-27 Evaluation of EI_{30} for the Chester Basin. 52
2-28 Average K Factor Values by Subbasin and County for the Chester River 53
2-29 Agricultural Data for Counties in the Chester River Basin for 1973. 55
2-30 Cover Factors for Various Intervals for the Chester River Basin 56
2-31 Soil Nutrient Concentrations in the Chester River Basin . . . 58
2-32 Estimated Stream Loading Rates for the Average Chester Event, Sediment Delivery Ratio = 0.1. 60
2-33 Patuxent River Subbasins. 61
2-34 Evaluation of EI_{30} for the Patuxent Basin 64
2-35 Average K Factor Values by Subbasin for the Patuxent Basin. . 65
2-36 Agricultural Data for Counties in Patuxent River Basin in 1973. 66
2-37 Estimated Areas of Principal Crop Rotations by County in Patuxent River Basin in 1973. 67
2-38 Cover Factors (C) for Crops by Rainfall Intervals and Counties for the Patuxent River Basin 69
2-39 Soil Nutrient Concentrations in the Patuxent River Basin. . . 71
2-40 Estimated Stream Loading Rates for the Average Patuxent Event, Sediment Delivery Ratio = 0.1. 72
2-41 Estimated Annual Loads for Urban Runoff: Patuxent River Basin 73
2-42 Ware River Subbasins. 74
2-43 Evaluation of EI_{30} for the Ware River Basin 76
2-44 Agricultural Data for Glouchester County (Ware River Basin), Virginia for 1977 78

TABLES (Cont'd)

Number		Page
2-45	Cover Factors (C) by Rainfall Interval for the Ware River Basin	78
2-46	Estimated Stream Loading Rates for the Average Ware Event; Sediment Delivery Ratio = 0.1	80
2-47	Occoquan River Subbasins.	81
2-48	Evaluation of EI_{30} for the Occoquan Basin	83
2-49	Agricultural Data for Counties in the Occoquan River Basin in 1973	85
2-50	Estimated Areas of Principal Crop Rotations by County in the Occoquan River Basin for 1973	86
2-51	Cover Factors (C) by Rainfall Interval and by Crop for the Occoquan River Basin.	86
2-52	Soil Nutrient Concentrations in the Occoquan River Basin. . .	88
2-53	Estimated Stream Loading Rates for the Average Occoquan Event	89
2-54	Estimated Annual Loads from Urban Runoff: Occoquan River Basin	89
3-1	Potomac River Basin Subwatersheds	98
3-2	Suspended Sediment Discharges, Potomac River.	99
3-3	Estimates of Average Annual Phosphorus Flux at Great Falls From Nonpoint Sources	103
3-4	Sensitivity of Annual Phosphorus Flux Estimates to Streambank and Gully Erosion	105
3-5	Susquehanna River Basin Subwatersheds	107
3-6	Suspended Sediment Discharge at Harrisburg.	108
3-7	Estimates of Average Annual Phosphorus Flux Into Reservoir Behind Safe Harbor Dam.	111
3-8	Estimates of Rural Nonpoint Source Flux of Phosphorus at the Mouth of the Susquehanna.	113
3-9	Estimates of Average Annual Phosphorus Fluxes	116

TABLES (Cont'd)

Number Page

I-1 Practice Factors by Land Use and Land Capability Class for Each County 129 129
I-2 Slope Length in Land Resource Area by Land Capability Class . 141 141
I-3 Slope in Land Resource Area by Land Capability Class. 142 142
II-1 Land Resource Areas Included in Study 144 144
III-1 English to Metric Conversion Factors. 145 145

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In August 1977 the U.S. Environmental Protection Agency (EPA) published a document entitled "Water Quality Assessment--A Screening Method for Nondesignated 208 Areas" (EPA-600/9-77-023). This document is a compendium of techniques designed to aid in the assessment of water quality problems in areas other than those covered under Section 208 of the Federal Water Pollution Control Act Amendments of 1972. Designated 208 areas are generally characterized by high concentrations of urban or industrial discharges, whereas nondesignated 208 areas may encompass a wider spectrum of human activities and, hence, a larger set of water quality conditions. These include agriculture and silviculture, as well as industrial and municipal activities. As a result, methods to assess water quality in nondesignated 208 areas must include not only the capability to predict impacts from point sources but also impacts from diffuse or nonpoint sources.

In the above EPA document, Tetra Tech, Inc., brought together a number of methods designed to accommodate both urban and non-urban nonpoint sources, as well as municipal and industrial point sources of pollutants. In addition to the assessment of effluent water quality, the methodology provided for systematic routing of these pollutants through rivers and streams, impoundments, and estuary systems. All algorithms were designed to be used as hand calculation tools.

In 1976 Midwest Research Institute (MRI) developed a document entitled, "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," for the U.S. Environmental Protection Agency (EPA-600/2-76-151). The loading functions described therein are used to estimate the quantities of different

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diffuse loads that enter receiving water bodies. These methods do not route pollutants through the receiving waters, however.

It appeared that the use of these two tools in concert might provide an adequate set of methods for screening nondesignated 208 areas by simple hand calculation procedures. The methods developed by MRI for analysis of diffuse sources of water pollution and the parallel methodology developed by Tetra Tech had never been applied together in an actual field situation. Thus, this study represents an application of both methods under realistic situations for the purpose of demonstrating how the methodologies may be used for identification of water quality problem areas in nondesignated 208 areas.

The vast majority of the data used in making the calculations in Volume I were in English units. Metric equivalents were not included in the text and tables because direct conversion of each English unit would produce numbers that are awkward and undesirable. Conversion of the Universal Soil Loss Equation (USLE) as a whole is more appropriate (Wischmeier and Smith, 1978). For the convenience of the reader, English to metric conversion factors for units used within this report are included in Appendix III.

1.2 PURPOSE AND SCOPE

The primary goal of this study is to demonstrate Midwest Research Institute's loading functions and Tetra Tech's nondesignated 208 screening procedures under authentic field situations. The demonstration is designed to subject the procedures to a wide range of data availability, water quality parameters, and hydrologic/hydraulic situations. In addition to the primary goal, there are several secondary goals. They are:

1. Provide a report demonstrating the 208 screening methodology to be used as a guide by planners.

2. Show the degree of compatibility between the nonpoint loading analysis and the 208 screening methodology.

3. Develop firmer insight into the strengths and weaknesses of the nonpoint loading methodology.

4. Evaluate the sensitivity of nonpoint load estimates to varying degrees of data availability.

5. Determine how critical or necessary the quality and quantity of nonpoint source details are with regard to reliably modeling instream processes as they are affected by nonpoint loading.

6. Demonstrate strengths and weaknesses of the 208 screening methodology.

It is worth emphasizing that the goal of this effort is to provide a demonstration of existing techniques--not to engage in methodology development. While some new approaches are incorporated in this study, by and large the approach follows that which has been documented earlier. The new approaches were added to overcome gaps in the existing methodology which would have restricted this demonstration.

1.3 FORMAT AND ORGANIZATION

This report consists of two volumes. Volume I is a discussion of the application of MRI's nonpoint load assessment methodology to a number of river basins. Volume II considers the application of the nondesignated 208 screening methodologies developed by Tetra Tech to these same basins. The nonpoint source load estimates given in Volume I are used as inputs to the calculations involving wet weather conditions that are presented in Volume II. The two volumes are organized similarly; the river basins are considered in the same order in both. There is cross-referencing in this volume to portions of Volume II so that the interested reader can see how results obtained in Volume I are used in the second volume.

Even though there is this connection between the two, each volume can stand alone as separate demonstrations of the different methodologies being examined. That is, a reader whose primary interest is water quality assessments in water bodies, and who is not concerned with estimation of nonpoint source loads, can use Volume II independently of Volume I. Similarly, a reader interested only in estimating nonpoint source loads would need Volume II only if concerned with how these loads are used in assessing impacts on water quality, or if interested in examining how such use can say something about the reliability of the nonpoint load estimates.

The nonpoint source loading functions used are not described in detail in either volume. Such information is available in the EPA report by McElroy et al. (1976). Only modifications or extensions of the loadings functions are considered in detail here. Loading functions were developed for a variety of sources, not all of which are examined in this demonstration. The watersheds considered allowed application of the methodologies for agriculture and urban areas. Other nonpoint sources such as river drainage, feedlots, and waste disposal areas were not examined.

This volume is divided into four chapters; the first chapter is the introduction. Chapter 2 discusses the demonstration of nonpoint loading techniques as applied to five watersheds. In the first application (to the Sandusky River Basin in Ohio) there is considerable discussion of the approach used. The discussions of the remaining applications are more abbreviated. It is, therefore, recommended that the interested reader carefully examine Section 2.1 for information on details and on the philosophy used in this study. Chapter 3 is a discussion of an approach, based on the loading function, for estimating nutrient fluxes in streams. The content of Chapter 3 is independent of the remainder of Volume I and also has no connection with Volume II. Finally, Chapter 4 contains a general discussion and conclusions based on the demonstration.

Following the development of the nonpoint loading functions by McElroy et al. (1976), EPA supported the development of a computer program called the "Nonpoint Calculator" (Davis et al., 1979). This is a programmed version of the original loading functions with some modifications and updating. It is intended for rapid application of the loading functions and is tied to a national data base at the county level of resolution. Use of the program and data base facilitates preliminary nonpoint source load assessments for large areas. The nonpoint calculator program was used to obtain the load estimates presented in this volume. Such use eliminated a considerable amount of tedious effort. The loading functions applied in this effort are intended for use in desktop calculations. In applications such as those described here, which cover many counties, the use of the computer program is advisable, however. All modifications in the approach used by the nonpoint calculator as compared with the original loading functions are noted in this volume, where appropriate.

CHAPTER 2

DEMONSTRATION OF METHODS

2.1 DEMONSTRATION EXAMPLE: THE SANDUSKY RIVER BASIN

2.1.1 Character of the Basin

The Sandusky River (Figure 2-1) is located in northwestern Ohio and discharges into the western end of Lake Erie. The basin, not including Green Creek, has an area of about 1,399 sq miles. The major land use is agriculture, and corn and soybeans are the principal crops. The river falls 520 ft in elevation from its source to its mouth and has a length of about 120 miles, giving an average fall of about 4 ft/mile.

The southern two-thirds of the basin is rather flat and is characterized by broken ridges (end moraines) left by glaciers during their retreat from the area. These ridges may be several miles wide and as high as 50 ft. The northern one-third of the basin is also rather flat or gradually rolling. As might be expected given such topography, the streams in the basin tend to be sluggish.

The basin receives an average of 34 in. of rain each year; the heaviest rainfall occurs during spring and early summer. The climate is humid continental with warm summers.

Figure 2-1 shows how the basin has been divided into subbasins for purposes of analysis. County boundaries are also shown. Table 2-1 provides some information on each of the subbasins.

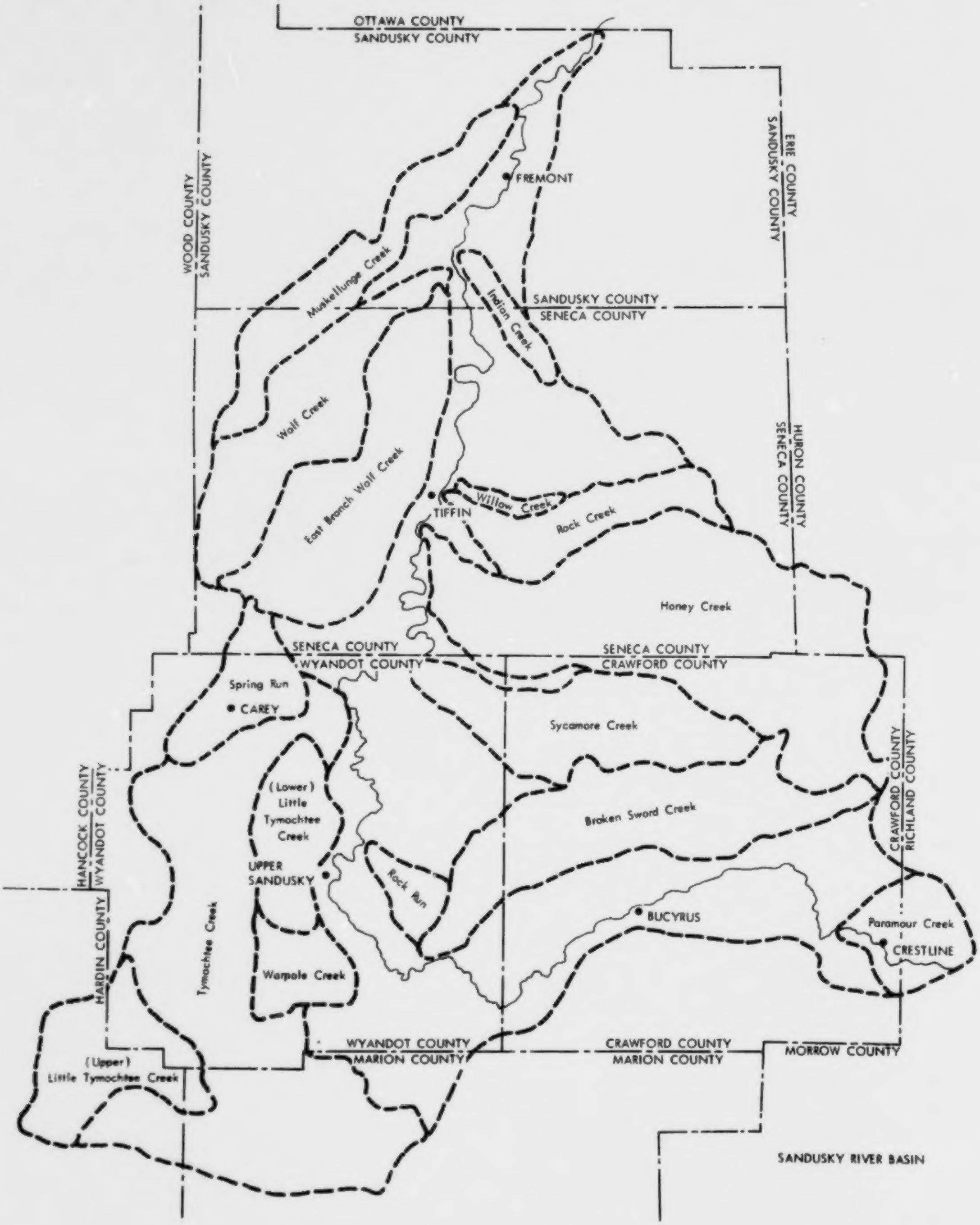
OTTAWA COUNTY
SANDUSKY COUNTY
WOOD COUNTY
SANDUSKY COUNTY
ERIE COUNTY
SANDUSKY COUNTY
FREMONT
Muskellunge Creek
Indian Creek
SANDUSKY COUNTY
SENECA COUNTY
Wolf Creek
East Branch Wolf Creek
HURON COUNTY
SENECA COUNTY
TIFFIN
Willow Creek
Rock Creek
Honey Creek
SENECA COUNTY
WYANDOT COUNTY
SENECA COUNTY
CRAWFORD COUNTY
Spring Run
CAREY
Sycamore Creek
HANCOCK COUNTY
WYANDOT COUNTY
(Lower) Little Tymochtee Creek
Broken Sword Creek
CRAWFORD COUNTY
RICHLAND COUNTY
UPPER SANDUSKY
Rock Run
HARDIN COUNTY
WYANDOT COUNTY
Tymochtee Creek
BUCYRUS
Paramour Creek
CRESTLINE
Warpole Creek
WYANDOT COUNTY
MARION COUNTY
CRAWFORD COUNTY
MARION COUNTY
MORROW COUNTY
(Upper) Little Tymochtee Creek
SANDUSKY RIVER BASIN

Figure 2-1. Sandusky River Basin.

TABLE 2-1. SANDUSKY RIVER SUBBASINS

	Area (mile²)[a]	Length of principal streams (miles)[b]
Paramour Creek	27.8	9.6
Broken Sword Creek	94.7	47.7
Rock Run	10.5	7.0
Sycamore Creek	64.2	23.9
Honey Creek	179.0	82.1
Upper Little Tymochtee Creek	49.6	26.1
Lower Little Tymochtee Creek	31.4	24.4
Warpole Creek	20.6	10.5
Spring Run	30.1	15.8
Tymochtee Creek (without tributaries)	170.3	104.4
Rock Creek	34.8	22.6
Willow Creek	5.7	5.0
East Branch Wolf Creek	84.5	31.0
Wolf Creek (without East Branch)	73.5	23.1
Muskellunge Creek	46.7	18.3
Indian Creek	11.8	7.5
Sandusky River:		
Crawford County	108.2	29.8
Wyandot County	166.6	45.4
Seneca County	79.5	32.6
Sandusky County	49.5	22.4
Total area	1,339.0	

[a] Source: Cross, William P., Drainage Areas of Ohio Streams, Supplement to Gazetteer of Ohio Streams, Ohio Department of Natural Resources, Ohio Water Plan Inventory, Report 12a, Columbus, Ohio, 1967.

[b] Source: Ohio Department of Natural Resources, Gazetteer of Ohio Streams, Ohio Water Plan Inventory, Report 12, 1960.

2.1.2 Nonpoint Load Estimation Methodology - An Overview

Several pollutant sources were considered in the analysis: runoff from rural lands; urban runoff; and combined sewer overflows. Average annual loads for urban runoff and combined sewer overflows were estimated for each of the major urban areas in the basin. The approach used is discussed in section 2.1.4. Feedlots were found to be an unlikely source of significant pollutant loads in the basin and were not considered in detail.

The most complex portion of the analysis involves pollution arising from the rural land surface. Estimates of pollutant loads were made on a subbasin basis. In making the calculations, the counties in the basin were assumed to be homogeneous in terms of land use (i.e., all land uses evenly distributed throughout the county) since land use information was not available below the county level of detail at the time the analysis was done. The assumption of homogeneity is not valid for many of the subbasins, but subdivision was necessary to determine areas delivering loads to particular stream segments.

Nonpoint loads from the land surface are delivered during and following rainstorm events that produce runoff. At such times the streams involved are usually experiencing high flow conditions. Since it is desirable to compare instream water quality changes with those expected based on the pollutant loads calculated, it is necessary to estimate loading rates during events. Longer term averages, while useful for some purposes, will not allow such comparisons to be made.

Based upon flow levels and the availability of water quality data, storm periods were selected by the Tetra Tech team for which nonpoint source loads were to be determined. It was necessary that the same periods be examined by those concerned with the load estimates and those examining instream effects. The periods selected were chosen so as to avoid the possibility of snowmelt occurring, since the methodology does not consider the erosion produced by melting snow. In the case of the Sandusky this consideration resulted in the analysis of events following only in the April to September time interval.

The rural nonpoint loads were determined using the assumption that pollutants are associated with sediment. Sediment loads were estimated with the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) used along with a delivery ratio. The USLE is intended to predict annual average soil loss. If applied to a particular storm event, it predicts the soil loss expected on average from many such events. It will not predict the loss from the individual event primarily because antecendent conditions are not considered. In the present study, event loads were estimated by averaging over a series of many storms of different characteristics. As indicated above, these storms were selected to assure consistency between the two phases of this effort: load estimation and instream effects.

Soil losses were estimated for each event in the series of storms, and these values were then averaged to give an average soil loss per event for the series of events studies. Whereas the estimates of soil loss per individual event will not provide good predictions of losses for those individual events, averaging over a series of events, with varying antecedent conditions, will tend to yield a representative average for the series, assuming the series of events is of sufficient length and covers a variety of antecedent conditions. This average soil loss is used to determine average pollutant loads for the series of events. These average loads can then be used along with average flows for the series of events to obtain estimates of instream concentrations, which may in turn be compared with observed values for such conditions. Because of the need to provide appropriate load estimates for the water quality analysis, the approach just outlined was used. Extending the analysis to obtain results concerning the frequency with which particular events occur could be an interesting addition but not considered since it did not relate directly to the primary goal of demonstration of the methodology.

Annual sediment delivery ratios were estimated based on available data. The average delivery ratio for the series of events studies was then assumed to be equal to the annual average value, although this tends to underestimate the delivery ratio for the average event. An average delivery ratio was estimated using measured sediment discharge near the mouth of the Sandusky and estimated average annual soil loss for the basin.

The calculations of soil loss for the counties were carried out using the nonpoint calculator (Davis et al., 1979). Initially, calculations were made using parameter values contained in the associated national data base. The estimates were then refined using improved parameters. This parameter refinement was carried out for the R, C, and K factors.* Land use characteristics were determined based on county agricultural statistics combined with land use data contained in the national data base.

A difficulty encountered in applying the methodology was the lack of available adequate land use information on the spatial scale needed for subwatersheds. The U.S. Corps of Engineers has land use information containing a very high level of resolution, but such information was not available in time to use in this study.

K factors were determined for soil associations within the basin, and then K values, averaged across soil associations, were found by subbasin. C values were determined for each of the primary crops in each of the principal crop rotations used. Values were determined for the time of year corresponding to each event.

Using event-related parameter values for R and C, soil loss was determined for each event studied. These losses were then averaged to give an average loss per event in the series. This value, along with the average delivery ratio for the basin, was used to estimate sediment loads to the streams in the basin.

Nutrients (phosphorus and nitrogen) were assumed to be transported along with the sediment; the enrichment was estimated using a relation developed by Menzel (1980). (See section 2.1.3.1.7.) Estimated enrichment on an event-by-event basis was determined. These values, weighted by soil losses, were then used to find an effective average enrichment ratio. Little variation was found among average ratios for different locations in the basin. Both phosphorus and nitrogen were considered in the application since they are both dealt with by the loading functions. It is recognized, however, that much of the nitrogen is transported in a soluble form. That is, it is not associated with sediment. Therefore, although results are presented for nitrogen for the sake of completeness, they are not expected to be accurate.

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* See section 2.1.3.1 for definitions of these factors.

2.1.3 Rural Nonpoint Sources

2.1.3.1 Parameter Evaluation

Determination of rural nonpoint source loads requires knowledge of a number of relevant factors. Soil loss is found using the USLE (Wischmeier and Smith, 1978). That equation is given by:

$$A = RKLSCP$$

where A = soil loss in T/acre/year*
R = rainfall factor
K = soil erodibility factor
L = slope-length factor
S = slope-steepness factor
C = cover and management factor
P = support practice factor

Sediment yield is then given by:

$$Y_s = \gamma A \text{ (T/acre/year)*}$$

where γ = sediment delivery ratio

Loads of sediment-associated pollutants are determined using expressions of the form

$$Y_p = f \cdot r \cdot [P] \cdot Y_s \text{ (T/acre/year)*}$$

where f = availability factor
r = enrichment ratio
$[P]$ = soil concentration of pollutant

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* The unit given is tons/acre/year. Actually, the time interval is the same as that for which the R in the USLE is evaluated. This is typically an average year. In this study an average event is used and the units become T/acre/average event.

In addition, for nitrogen, input from rainfall is considered. Since some of the factors are a function of land use, land use statistics must be available.

The following sections describe in detail how the various parameters in the above equations were evaluated for the Sandusky River Basin.

2.1.3.1.1 Rainfall Factor (R)

For a particular rainstorm the rainfall factor is defined as the product of the total storm energy (E) and the maximum 30-minute rainfall intensity (I_{30}) for the storm (Wischmeier and Smith, 1978). To determine E, the storm periods were first divided into intervals with approximately uniform rainfall intensity in each. E was calculated for each interval using the following expression:*

$$E = (916 + 331 \log_{10} I) \cdot (\text{Rainfall in interval, in inches})$$

where I = rainfall intensity in in/h during an interval. The values of E for each interval were summed to give a total E for the storm.

Average annual R can be determined from maps. Annual values are the sum of storm values for EI_{30} for a year, averaged over a 22-year period.

Values for EI_{30} were determined using the above definition for the events of interest. Rainfall records from Fremont, Ohio, were used to find EI_{30}. A better approach would have been to consider the nonhomogeneity of rainfall statistics over the basin; however, the effort involved would have been considerably increased. It was assumed that on the average, rainstorm characteristics are the same basinwide and that averaging EI_{30} values at any point would give the same values.

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* The expression applied only for intensities less than 3 in/h. For higher intensities I is the expression is set equal to 3 in/h.

Table 2-2 shows the periods analyzed, the total rainfall at Fremont, and the value of EI_{30} for each interval at Fremont. To obtain EI_{30} it was necessary to analyze the actual rainfall records,* since published data provide rainfall only at 1-h intervals. For the three events with nonzero EI_{30}, for which the records were of sufficient quality to estimate EI_{30}, the average value of EI_{30} is 12.1. Without the single largest value of EI_{30}, the average is 8.4. The storm periods studied are distributed throughout the interval of April to September.

TABLE 2-2. EVALUATION OF EI_{30} FOR THE SANDUSKY BASIN

	Total rainfall at Fremont (inches)	EI_{30} for Fremont
May 16 - 22, 1969	3.41	23.7
July 5 - 11, 1969	poor records	
March 31 - April 6, 1970	1.42	7.5
June 14 - 21, 1970	3.96	56.8
May 4 - 10, 1971	0.97	2.5
April 15 - 22, 1972	2.69	13.3
May 12 - 18, 1972	0.90	2.6
June 18 - 24, 1973	0.76	1.6
June 30 - July 6, 1973	0.75	4.6
March 29 - April 5, 1974	0.92	6.6
August 29 - September 4, 1975	2.04	9.2
July 6 - 12, 1976	0.17	~ 0
March 31 - April 6, 1977	0.87	1.9
May 2 - 8, 1977	1.97	8.9
April 17 - 23, 1978	poor records	
May 19 - 25, 1978	1.64	18.7
Total	22.5	157.9

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* Rainfall records were obtained from the National Climatic Center, Asheville, North Carolina.

Based on maps of R, the average annual value for the Sandusky Basin is roughly 125. The average annual value decreases somewhat from the southern to the northern end of the basin. Based on an annual average of 125, the average storm with an EI of 12.1 produces about 10% of the annual soil loss.

2.1.3.1.2 Soil Erodibility Factor (K)

A weighted soil erodibility factor (K) for the subbasins in the Sandusky River Basin was calculated using three sources of information:

1. Generalized county maps showing the soil associations in the county (Ohio Department of Natural Resources).

2. A breakdown of the soil series comprising the soil associations in a county (Ohio Department of Natural Resources).

3. A list of K factors for each soil series (U.S. Department of Agriculture, 1979).

A planimeter was used to determine the proportion of a subbasin occupied by a soil association. An approximate K value for each soil association was determined by multiplying the K values of each soil series in a particular soil association by the respective fraction with which they occurred in the association, and then summing these numbers to obtain the weighted K. Each soil association contains a number of minor soils for which only a composite percentage of occurrence is given; all minor soils were assumed to have equal representation when the soil association K value was calculated.

The Blount-Pewamo Association in Crawford County can be used as an example. The Blount series has a K of 0.43 and comprises 35% of the association. The Pewamo series has a K of 0.24 and comprises 25%. The composite of minor soil series is 40% and five minor series are listed. The average K for the five minor series is 0.38. The weighted K for the association is the sum of the products of the K values for each series and the fraction of the total which each series comprises which gives 0.36.

The weighted K for a subbasin is simply the sum of the products of the soil association average Ks and the fractional areas of each association in the subbasin. Table 2-3 shows average values obtained in this manner for each of the subbasins (by county). Richland and Huron Counties were not included because of the small areas involved.

TABLE 2-3. AVERAGE K FACTOR VALUES BY SUBBASIN FOR THE SANDUSKY

Subbasin	Average K values by county					
	Sandusky	Seneca	Wyandot	Crawford	Hardin	Marion
Paramour Creek	-	-	-	0.36	-	-
Broken Sword Creek	-	-	0.39	0.35	-	-
Rock Run	-	-	0.38	-	-	-
Sycamore Creek	-	-	0.37	0.37	-	-
Honey Creek	-	0.39	0.38	0.36	-	-
Upper Little Tymochtee Creek	-	-	0.36	-	0.36	0.36
Lower Litte Tymochtee Creek	-	-	0.35	-	-	-
Warpole Creek	-	-	0.38	-	-	-
Spring Run	-	0.38	0.36	-	-	-
Tymochtee Creek (without tributaries)	-	-	0.37	-	0.38	0.34
Rock Creek	-	0.38	-	-	-	-
Willow Creek	-	0.37	-	-	-	-
East Branch Wolf Creek	0.22	0.35	-	-	-	-
Wolf Creek (without East Branch)	0.23	0.34	-	-	-	-
Muskellunge Creek	0.29	0.32	-	-	-	-
Indian Creek	0.20	0.28	-	-	-	-
Sandusky River	0.28	0.33	0.36	0.37	-	0.34

2.1.3.1.3 Slope Factors (L and S)

Slopes and slope lengths were obtained for the nonpoint calculator data base. That data base contains slopes and slope length by Land Resource Area (LRA) (Austin, 1972). The basin is located in LRAs 99 and 111: the Erie-Huron Lake Plain and the Indiana and Ohio Till Plain. LS was determined by the nonpoint calculator using the algorithm described in the documentation for that program (Davis et al., 1979). The slopes and slope lengths used are tabulated in Appendix I.

2.1.3.1.4 Cover Factor (C)

Since soil loss estimates for particular events are needed, it is necessary to estimate values for the cover factor at the time of the runoff events. Cropland is the primary source of sediment, so it is necessary to know which crops are present, what rotations they are in, and what stage in the rotation applies at the time of the rainfall event.

There are four principal crops in the basin: soybeans, corn, wheat and oats. These crops, plus hay, are likely to be in one of seven different rotations. The approach for determining the quantity of each crop in each rotation is based on the analysis by Logan (1978). The total acreages of each crop were obtained from county agricultural statistics. Crop statistics from 1969 to 1977 were examined. The year 1975 was selected as typical of that interval. (Land use considerations are discussed in section 2.1.3.6 below.) Table 2-4 shows county statistics for 1975 for the basin. (Huron, Richland, and Hardin Counties are not considered in this analysis since they constitute such small portions of the basin.) Based upon county crop data and discussions with county extension agents, the predominant cropping practices within each county in the basin were established and some assumptions made as to crop acreage distributions. These are:

TABLE 2-4. AGRICULTURAL DATA FOR COUNTIES IN THE SANDUSKY BASIN IN 1975

County	Crop area (10^3 acres) Corn	Soybeans	Wheat	Oats	Hay	Total
Sandusky	55.2	63.3	32.0	7.5	10.7	168.7
Seneca	64.5	91.8	52.1	14.3	16.0	238.7
Wyandot	57.5	73.9	48.3	6.4	10.0	196.1
Crawford	57.8	57.4	31.0	10.8	11.8	168.8
Marion	67.7	79.6	31.6	7.2	8.7	194.8

Source: Ohio Agricultural Research and Developement Center, Ohio Agricultural Statistics 1970-75, Research Bulletin 1106, Wooster, Ohio, 1978.

1. All wheat is in a corn-soybean-wheat rotation: C Sb W.

2. Fifty percent of the hay harvested is in the rotations: M C Sb W (M meadow).

3. All oats are planted in the spring after beans: C Sb O W.

4. Any remaining corn and soybeans after No. 3 above are in C Sb rotation.

5. Any remaining corn or soybeans after No. 4 above are in continuous corn or soybeans.

6. Fifty percent of hay harvested is in permanent pasture.

The seven crop rotations predominantly used in the basin are:

C Sb W
M C Sb W
C Sb O W
C Sb
Continuous C
Continuous Sb
Permanent pasture

The crop statistics shown in Table 2-4 plus the assumptions given above are sufficient to determine the areas in each of the seven rotation patterns. These areas are determined as follows:

1. Area in C Sb O W = 4 x area in oats.

2. Area in M C Sb W = 4 x (0.5 x area in hay).

3. Permanent pasture = 0.5 x area in hay.

4. Area in C Sb W = 3 x (area in wheat - area in oats - 0.5 x area in hay).

5. Area in C Sb = 2 x (lesser of area in C or area in Sb - area in wheat).

6. If area in Sb > area in C, area in continuous Sb = area in Sb minus area in C.

7. If area in C > area in Sb, area in continuous C = area in C minus area in Sb.

The results are shown in Table 2-5.

TABLE 2-5. ESTIMATED AREAS OF PRINCIPAL CROP ROTATIONS BY COUNTY IN THE SANDUSKY RIVER BASIN FOR 1975

	Area in rotation (10^3 acres)						
County	C Sb W	M C Sb W	C Sb O W	C Sb	Cont. C	Cont. Sb	Permanent pasture
Sandusky	57.6	21.2	30.0	46.4	-	8.1	5.3
Seneca	89.4	32.0	57.2	24.8	-	27.3	8.0
Wyandot	110.7	20.0	25.6	18.4	-	16.4	5.0
Crawford	42.9	23.6	43.2	52.8	0.4	-	5.9
Marion	60.0	17.6	28.8	72.2	-	11.9	4.4

Note: C = corn;
Sb = soybeans;
W = wheat;
M = meadow.

Cover factors were determined using the results presented by Wischmeier and Smith (1978). Results are presented there in terms of each crop and the crop it follows in rotation. Application of the results requires knowledge about the development of each crop throughout the period of interest, namely

April through September. Table 2-6 provides an example of the determination of the cover factor for corn after soybeans. Similar tables were developed for each crop in each rotation (e.g., corn after hay, corn after wheat, beans after corn, beans after beans, corn after beans, oats after beans, wheat after corn, wheat after beans, etc.).

TABLE 2-6. DETERMINATION OF COVER FACTOR FOR CORN AFTER SOYBEANS BY CROP STAGE

Time interval	Period[a]	Soil loss ratio[b]	Line used[c]	Comment
March to mid-April	4	0.38	Table 5-C	Assume 40% mulch
Mid-April to late April	F	0.47	110	Plowed with moldboard
Late April to mid-May	SB	0.78	110	Plant
Mid-May to mid-June	1	0.65	110	10 to 50% canopy cover
Mid-June to late July	2	0.51	110	50 to 75% canopy cover
Late July to mid-October	3	0.30	110	90% canopy at harvest
Mid-October to mid-April	4	0.37	110	-

Source: Wischmeier and Smith (1978), pp. 18-26; assumes good productions, spring-plowed with moldboard, and conventional tillage.

[a] F = rough fallow; SB = seed bed; 1 = establishment; 2 = development; 3 = maturing crop; 4 = residue or stubble (see Wischmeier and Smith for complete definitions).

[b] Ratio of loss from crop stage as compared to clean-tilled, continuous fallow. These values are cover factors for the time interval indicated.

[c] Line used from Table 5 or 5-C of Wischmeier and Smith.

The cover factors (soil loss ratios) for each crop in each rotation were then weighted by the fraction of the total crop in each rotation to give an average cover factor for each time interval for each crop. Tables 2-7 through 2-9 show the results for corn, soybeans, and grain (wheat and oats).

Examination of Table 2-2 shows that the events can be placed into five time groups: early April, late mid-April, May, late June to early July, and September.

TABLE 2-7. COVER FACTORS FOR CORN FOR THE SANDUSKY BASIN

County	March to mid-April	Mid-April late April	Late April to mid-May	Mid-May to mid-June	Mid-June to late July	Late July to October
Sandusky	0.20	0.41	0.68	0.58	0.45	0.27
Seneca	0.12	0.39	0.64	0.55	0.43	0.25
Wyandot	0.20	0.43	0.69	0.59	0.46	0.27
Crawford	0.25	0.44	0.72	0.61	0.47	0.28
Marion	0.30	0.45	0.74	0.62	0.49	0.29
Average	0.21	0.42	0.69	0.59	0.46	0.27

TABLE 2-8. COVER FACTORS FOR SOYBEANS FOR THE SANDUSKY BASIN

County	March to mid-April	Mid-April to late April	Late April to mid-June	Mid-June to mid-July	Mid-July to early August	Early August to October
Sandusky	0.37	0.40	0.66	0.57	0.42	0.22
Seneca	0.37	0.41	0.68	0.59	0.44	0.24
Wyandot	0.37	0.41	0.67	0.58	0.43	0.23
Crawford	0.37	0.39	0.64	0.56	0.41	0.21
Marion	0.37	0.40	0.66	0.57	0.42	0.22
Average	0.37	0.40	0.66	0.57	0.42	0.22

TABLE 2-9. COVER FACTORS FOR GRAIN FOR THE SANDUSKY BASIN

County	March	April	Early May to mid-May	Mid-May to mid-June	Mid-June to mid-July	Mid-July to August 1	August 1 to late September
Sandusky	0.34	0.35	0.19	0.17	0.09	0.06	0.07
Seneca	0.34	0.36	0.20	0.18	0.10	0.06	0.07
Wyandot	0.34	0.35	0.17	0.16	0.07	0.07	0.07
Crawford	0.34	0.36	0.22	0.19	0.10	0.06	0.07
Marion	0.34	0.35	0.19	0.17	0.09	0.06	0.07
Average	0.34	0.35	0.19	0.17	0.09	0.06	0.07

Perusal of Tables 2-7 through 2-9 indicates that in most cases, C does not vary much from county to county within the basin for given crops and given time intervals. These observations allow the soil loss calculations to be considerably simplified by using a limited number of C values. Table 2-10 indicates average values for use for each group of events.

TABLE 2-10. COVER FACTORS BY EVENT AND BY CROP FOR THE SANDUSKY BASIN

Group of Events	Crop Corn	 Beans	 Grain
Early April	a	0.37	0.35
Mid to late April	0.42	0.40	0.35
May	0.64	0.66	0.18
Late June to early July	0.46	0.57	0.09
Early September	0.27	0.22	0.07

[a] Use values given in Table 2-7.

In addition, long-term average values for C for the major crops were determined. This involved averaging over counties and rotations. The averaged soil loss ratios were then weighted by the fraction of EI in each time interval to give values for C. The average values are 0.39 for corn and soybeans and 0.10 for small grains.

The final results of the C factor evaluation are in Table 2-10. These values will be used below along with the other factors to determine soil loss by event.

2.1.3.1.5 Support Practice Factor (P)

Conservation needs were identified during the 1967 conservation needs inventory (CNI) on a county-by-county basis. These data were used to develop P factor values for the nonpoint calculator data base. Those values for the counties in the Sandusky Basin were used in this analysis and are given in Appendix I. The P values are defined in the data base as a function of land use and land capability class. The land uses and capability classes used are listed in Table 2-11.

It has been assumed that no significant change in conservation treatment needs occurred from the time of the 1967 CNI to the period of interest for this study, 1969 to 1978. This assumption was necessary since the information needed to update the description of practices was not readily available.

2.1.3.1.6 Land Use Within the Sandusky Basin

Since detailed land use data for the Sandusky Basin were not available in time for this study, the land use data used were based on county agricultural statistics augmented by data from the nonpoint calculator data base. The principal assumption used in the analysis was that land use within each county is homogeneous. This is apparently a reasonable assumption. However, it is very likely unfair to assume that a uniform distribution of land use can be applied to many of the smaller subbasins studied. Therefore, loads estimated for these small subbasins could be in considerable error if the land use in the subbasin differs substantially from average.

The land use data base for the nonpoint calculator considers 16 land uses and the 29 land capability classes and subclasses (Table 2-11) and was developed on a county-by-county basis using the 1967 CNI results for each state. Preliminary calculations using the data base with no updating indicated that the primary sources of soil loss were land uses 1 through 3--agricultural uses. Since these were the critical areas, an effort was made to update the land use information in these categories.

Land use changes have occurred over the study period of nearly 10 years. It would be a considerable effort to account for such changes each year. Instead, a typical year having land use patterns similar to the average over the period was chosen. Soybeans and corn are the dominant crops; and Sandusky,

TABLE 2-11. LAND CAPABILITY CLASSES[a] AND LAND USES

Twenty-nine land capability classes[b]	Sixteen land uses
Class I-	Corn and sorghum
Class II	Other row crops
Class III	Close-grown crops
Class IIw	Summer fallow
Class IIc	Rotated hay and pasture
Class IIIe	Hay only
Class IIIs	Conservation use only
Class IIIw	Temporarily idle
Class IIIc	Orchards
Class IVe	Open, formerly cropped
Class IVs	Pasture
Class IVw	Range
Class IVc	Other farmland
Class Ve	Other non-farmland
Class Vs	CNI commercial forest
Class Vw	CNI noncommercial forest
Class Vc	
Class VIe	
Class VIs	
Class VIw	
Class VIc	
Class VIIs	
Class VIIs	
Class VIIw	
Class VIIc	
Class VIIIe	
Class VIIIs	
Class VIIIw	
Class VIIIc	

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[a] The classification below follows that used in the Conservation Needs Inventory (CNI).

[b] Land capability classes are defined as follows:

Class I.	Soils have few limitations that restrict their use.
Class II.	Soils have moderate limitations that reduce the choice of plants or require moderate conservation practices.

(continued)

TABLE 2-11. (continued)

Class III.	Soils have severe limitations that reduce the choice of plants, require special conservation practices, or both.
Class IV.	Soils have very severe limitations that reduce the choice of plants, require very careful management, or both.
Class V.	Soils are subject to little or no erosion but have other limitations, impractical to remove, that limit their use largely to pasture, range, forest, or wildlife food and cover.
Class VI.	Soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, forest, or wildlife food and cover.
Class VII.	Soils have very severe limitations that make them unsuited to cultivation and that restrict their use largely to pasture or range, forest, or wildlife food and cover.
Class VIII.	Soils and landforms have limitations that preclude their use for commercial plants and restrict their use to recreation, wildlife, or water supply, or to aesthetic purposes.

Subclasses describe a grouping of soils within one class having similar kinds of limitations. Four kinds of limitations are recognized and are designated and defined as follows:

"e" shows that the main limitation is risk of erosion.
"w" shows that water in or on the soil interferes with plant growth or cultivation.
"s" shows that the soil is limited because it is shallow, droughty, or stony.
"c" shows that the chief limitation is climate that is too cold or too dry.

Seneca, Wyandot, Crawford, and Marion are the major counties in the basin. Average acreages of corn and soybeans were determined for each of these counties for the 1969 to 1977 interval. These averages correspond closely to the acreages for 1975, so 1975 was used in the analysis.

Table 2-12 shows average land use (1969 to 1977), land use for 1975, and the 1967 CNI data for the counties. Since the nonpoint calculator data base (1967 CNI data) breaks each land use category into areas by land capability class, which is compatible with the way the parameters in the soil loss equation are defined in the nonpoint calculator, it was decided to modify all new land use information into a form compatible with the original data base. To do this required several assumptions: (a) the overall distribution of land by capability class does not change; (b) when land uses are changed the land shifted from one use to the other is taken from each capability class in proportion to the amount in that class; (c) if land use additions for uses 1 to 3 exceed land available in categories labeled "conservation use only" or "temporarily idle," land is shifted from "open, formerly cropped," or forest lands given in the 1967 CNI. With the exception of Sandusky County, agricultural land uses (uses 1 to 3) increased from 1967 to 1975. Therefore, shifts from the other categories to crops are necessary. There are no data indicating which land uses were shifted, but the shifts chosen seem reasonable.

The specific land use changes are outlined below by county.

Sandusky County: There was a 4,800-acre decrease of corn acreage from 1967 to 1975, along with a 15,000-acre decrease of soybeans and a 11,600-acre increase of close-grown crops. All the decrease in corn acreage was assumed to be shifted to close-grown crops, and the balance of the decrease in soybean acreage was assumed to go to the temporarily idle category.

Seneca County: The decrease in corn production was shifted to soybeans, and land from the conservation use category was shifted to accommodate the increased production of soybeans and close-grown crops.

TABLE 2-12. LAND USES IN THE SANDUSKY BASIN

	10^3 acres				
	Corn	Other row crops (soybeans)	Close-grown crops (oats and wheat)	Conservation use only	Temporarily idle
Sandusky County					
Average	53.4	66.7	-	-	-
1975	55.2	63.3	39.5	-	-
1967-CNI	60.0	78.3	27.9	21.9	1.0
Seneca County					
Average	65.6	92.9	-	-	-
1975	64.5	91.8	66.4	-	-
1967-CNI	73.5	77.2	52.0	32.1	0.3
Wyandot County					
Average	57.1	71.6	-	-	-
1975	57.5	73.9	54.7	-	-
1967-CNI	54.0	50.8	31.8	21.7	12.8
Crawford County					
Average	54.9	60.9	-	-	-
1975	57.8	57.4	41.8	-	-
1967-CNI	60.9	41.0	31.6	16.1	-
Marion County					
Average	66.3	76.5	-	-	-
1975	67.7	79.6	38.8	-	-
1967-CNI	66.0	44.9	35.1	13.4	3.1

Note: Hyphens indicate no data available.

Wyandot County: The large increases in crop production were accommodated by shifts from conservation use, temporarily idle, open formerly cropped, and forestlands.

Crawford County: Decreased corn production allowed a shift to soybeans. Land from conservation use and rotated hay and pasture were shifted to soybean and small grain production.

Marion County: Corn area was left unchanged; all temporarily idle, conservation use, open formerly cropped, and the decreased area in rotated hay and pasture were shifted to soybeans and small grains.

The land use shifts were somewhat arbitrary. However, the total land area was held constant and the total area in each capability class was also maintained constant. When crop production increased, land was added from what seemed to be the most available category. The fact that the primary soil losses come from the cropped areas means that the most sensitive issue is the area of crops used. The other land uses from which land might be drawn have low soil losses and the final results are not sensitive to the actual land use from which cropland is taken.

Because the portions of Hardin and Richland counties contained in the basin are very small fractions of the total areas of those counties, it does not seem appropriate to try to update land uses in those areas. The assumption of homogeneous land use throughout the counties would probably not apply to those small areas. The 1967 CNI data were used for the two counties.

2.1.3.1.7 Nutrients

In addition to the information need to determine soil loss, three other items are needed to determine loads of nutrients, namely the soil concentration of the nutrient, the enrichment ratio, and, for nitrogen, the input due to rainfall.

2.1.3.1.7.1 Determination of Enrichment Ratio

The following relationship between the enrichment ratio for nutrients and soil loss has been developed by Menzel (1980):

$$\ln (r) = 2 - 0.2 \ln (A)$$

where r = enrichment ratio
A = soil loss in kg/ha for individual events

The relationship predicts r for actual events; the higher the soil loss, the less the enrichment. The relationship appears to be valid over a wide range of soil and vegetative conditions. Annual average enrichment ratios estimated using the expression should be accurate to within a factor of 2.

Values of r were determined for each event for each county. An average soil loss weighted value of r ($r = \Sigma(rA)/A$) was determined for each county. The average value of r for the counties is 1.96 with a standard deviation of 0.08. Because of the small variation from county to county and the rather uncertain nature of the value for r, a value of r equal to 2 has been used in the analysis. This average value used with average soil loss and soil nutrient concentrations will provide an estimate of the total nutrient load for the actual series of events studied.

2.1.3.1.7.2 Nutrient Concentrations

Soil nutrient concentrations were estimated or obtained for each county in the basin. Table 2-13 shows the values used. Total soil phosphorus concentrations for the Sandusky Basin are in the range 600 to 700 ppm;* a value of 650 ppm was used for calculations here. It is worth noting that the nonpoint calculator data base has a value of 660 ppm for total soil phosphorus concentration for the basin.

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* Personal Communication with Terry Logan, Soil Scientist, Department of Agronomy, Ohio State University, Columbus, Ohio, 1979.

TABLE 2-13. SOIL NUTRIENT CONCENTRATIONS IN THE SANDUSKY RIVER BASIN

County	Average nutrient concentration in soil (ppm)	
	Available phosphorus[a]	Total nitrogen[b]
Sandusky	30	1,880
Seneca	20	1,880
Wyandot	23	1,860
Crawford	23	1,960
Marion	23	1,790
Huron	27	1,950
Richland	23	1,950
Hardin	20	1,940

[a] Source: Logan, Terry J., "Levels of Plant Available Phosphorus in Agricultural Soils in the Lake Erie Drainage Basin," Army Corps of Engineers, Lake Erie Wastewater Management Study, December 1977. Total soil phosphorus concentrations average 650 ppm (see Text).

[b] Source: Calculated using Jenny's Equation (Jenny, 1930); Ten percent of total nitrogen is assumed to be available.

Concentrations of available phosphorus were obtained from Logan (1977). Total nitrogen was determined using an expression developed by Jenny (1930). His equation relates soil nitrogen concentration to temperature, precipitation, and relative humidity:

$$C_S(NT) = 0.55\, e^{-0.08T} (1 - e^{-0.005H})$$

where $C_S(NT)$ = concentration of soil nitrogen, g/100 g
T = annual average temperature, °C

$$H = \frac{P}{(1 - \frac{RH}{100})\, SVP_t}$$

where P = precipitation, mm/year
RH = relative humidity, %
SVP_t = saturated vapor pressure at given temperature, mm of Hg

SVP_t and T are related by (McElroy et al., 1976):

$$SVP_t = 10^{[9.2992 - 2360/(273 + T)]}$$

Using county portions of each subbasin, soil concentrations of the nutrients were determined for each subbasin. Values for BOD_5 were estimated based on the nitrogen concentration. Organic matter concentrations of 20 times N_T were assumed. This procedure gives organic matter concentrations of about 4% in the soil, which appears reasonable based on the limited data available in soil surveys. However, the basin is predominantly agricultural, and the oxidation of the organic matter in such areas should reduce the organic matter concentrations; hence, the estimate based on 20 times N_T is probably high. BOD_5 was estimated as 10% of organic matter, or $2N_T$. Ten percent of total soil nitrogen was assumed to be available.

2.1.3.1.7.3 Rainfall Nitrogen

Nitrogen contained in rainfall was estimated from the data presented in McElroy et al. (1976). A loading rate of 2.7 lb/acre/year was used. It was assumed that such loading is distributed throughout the year in proportion to rainfall. Since the average annual rainfall is 30.25 in. at Fremont and since the series of events studied had a total of 22.5 in., a value of 2.0 lb/acre is estimated for the series of events studied.

For the Sandusky Basin, based on annual precipitation and annual discharge, 30% of the rainfall leaves the basin as runoff. Assuming that 20% of the runoff is in overland flow;* 6% of the N in rainfall appears in the runoff. Assuming that 25% of the nitrogen in overland flow is lost gives an average per event load (based on 14 events) of 0.0064 lb/acre.

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* Following McElroy et al. (1976) it is assumed that only that portion of rainfall nitrogen contained in overland flow reaches a stream. The fraction of runoff which follows the overland route varies from basin to basin and storm to storm. Proper evaluation of the fraction of the runoff which is in overland flow would require the detailed examination of hydrograph for the basin (actually, for various parts of the basin) for the events of interest. Because of the level of effort involved in determining the amount of overland flow and because the loading functions being applied are not well suited to estimation of nitrogen loading, it was merely assumed that only a fraction of runoff was in the form of overland flow and 20% was used arbitrarily.

2.1.3.1.8 Sediment Delivery Ratio

Sediment discharge data are available for a sampling location near Fremont. An area of 1,251 sq miles lies above that location, and the annual average sediment discharge at that location is 226,000 tons/year based on 6 years of U.S. Geological Survey data. Using this information along with an estimate of the annual average soil loss in the basin, an average basinwide sediment delivery ratio may be estimated.

Using an average rainfall factor of 125 along with the updated average K and C values and 1975 land use information gives a gross annual soil loss for the basin (1,339 sq miles) of 2.23×10^6 tons/year.

Mildner (1978) estimates that 7% of the total sediment yield of the Maumee River is from streambank erosion. The Maumee is located near the Sandusky, and a similar relationship will be assumed to apply there as well.

Extrapolating the sediment discharge data to the entire watershed (1,339 sq miles), using the soil loss given above, and assuming that 7% of the sediment discharged originated in streambank erosion, gives a sediment delivery ratio for the basin equal to 0.10. This is an estimate of the average annual basinwide ratio based on limited sediment discharge data.

It would be preferable to have delivery ratios within each subbasin and by season or month. Unfortunately such information is not available. Use of a basinwide delivery ratio for subbasins will tend to result in an underestimation of delivery ratios for subbasins in upland areas. Apparently, the efficiency of delivery of sediment is rather uniform in the basin (David Baker, personal communication), so the use of the basin average is a reasonable assumption throughout the basin. There is no similar simple approach for dealing with any seasonal variations in sediment delivery.

In the calculations in the following section a delivery ratio of 0.10 will be used.

2.1.3.2 Load Determination

The various factors involved in determination of pollutant loads have been discussed in the preceding section. Ideally, the parameters should be evaluated at field scale. However, the data and time limitations and the overall philosophy of the approach being pursued are inconsistent with such an effort. Table 2-14 shows the spatial level of resolution associated with various important factors in the study. Because the analysis is built around the USLE and because the USLE is intended for use at field scale, the high level of aggregation used in determining the various parameters results in inaccuracies in the analysis compared with what would be expected if all computations have been made at the field level. Although decreasing the reliability of the results, such inaccuracies are unavoidable if a screening approach is used.

TABLE 2-14. RESOLUTION ASSOCIATED WITH IMPORTANT PARAMETERS IN RURAL NONPOINT ANALYSIS

Parameter	Level of spatial resolution used
Rainfall factor (R)	River basin
Soil erodibility factor (K)	Subbasin
Slope factors (LS)	LRA (by land capability class)
Cover factor (C)	County, but averaged to river basin (by land use)
Support practice factor (P)	County (by land use and capability class)
Areas in particular land use	County
Delivery ratio	River basin (annual value)
Soil nutrient concentrations	County and river basin
Rainfall nitrogen input	River basin
Enrichment ratio	River basin

[a] LRA = Land resource area

Table 2-14 shows that except for the K and LS factors, all information relates to the county or river basin scale. Therefore, the only difference between unit area loads determined for the subbasins results from differences in the Ks. Given the data available, the analysis does not really distinguish between various portions of the basin in terms of unit area loads.

However, a definite distinction is made between loading rates per river mile in different subbasins. Unit area loads were determined for each subbasin. The subbasin areas given in Table 2-1 were then used to find total loads by subbasin. This subbasin load was divided by the length of the stream in the subbasin (as given in Table 2-1) to obtain a total average event load per unit length of stream channel in each subbasin. This load per length of channel was multiplied by the delivery ratio to obtain the quantity of material actually delivered to the stream channel. (Note that the basinwide average delivery ratio is being used for each subbasin. See section 2.1.3.1.8 above for a discussion of this point.

Table 2-15 shows the results obtained, by subbasin, for the average event considered. For the entire basin, the sediment load is 3.0×10^4 ton/event, the total phosphorus load is 7.9×10^4 lb/event, and the available phosphorus load is 3.0×10^3 lb/event.

Livestock feeding operations in the Sandusky River Basin are located almost exclusively in confined, surfaced, partially covered feedlots that have runoff control.* A number of environmentally sound practices are used for the treatment and disposal of the feedlot runoff (Livestock Waste Facilities Handbook, 1975). Consequently, its contribution as a pollutant source to surface streams in the basin is minimal. Runoff from feedlots was therefore neglected in the analysis.

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* Personal Communication with David Reed, Extension Livestock Specialist, Northwest Ohio Livestock Extension Office, Ohio State University, Defiance, Ohio, May 1, 1979.

TABLE 2-15. ESTIMATED STREAM LOADING RATES FOR THE AVERAGE SANDUSKY EVENT, SEDIMENT DELIVERY RATIO = 0.1

	tons/mile/event	lb/mile/event				
		Phosphorus			Nitrogen	
Subbasin	Sediment	Total	Available	BOD$_5$	Total	Available
Paramour Creek	58	150	5.4	900	460	56
Broken Sword Creek	49	130	4.5	770	400	47
Rock Run	49	130	4.6	730	370	42
Sycamore Creek	67	170	6.2	1,000	510	63
Honey Creek	43	110	3.7	660	340	42
Upper Little Tymochtee Creek	43	120	3.6	660	340	41
Lower Little Tymochtee Creek	40	110	3.6	600	310	35
Warpole Creek	65	170	6.0	960	490	56
Spring Run	54	140	4.8	800	410	48
Tymochtee Creek (without tributaries)	45	120	4.2	680	350	41
Rock Creek	28	73	2.2	430	220	27
Willow Creek	19	49	1.5	300	160	20
Wolf Creek, East Branch	45	120	3.5	670	350	45
Wolf Creek (without East Branch)	50	130	4.1	750	390	51
Muskellunge Creek	35	94	3.7	520	220	38
Indian Creek	15	37	1.4	220	120	19
Sandusky River						
Above Grass Run (Crawford County)	88	220	8.1	1,300	680	84
Below Grass Run, above Mexico (Wyandot County)	120	300	11.0	1,700	860	100
Below Mexico, above Wolf Creek (Seneca County)	37	97	3.0	560	290	38
Below Wolf Creek to the mouth (Sandusky County)	28	74	3.4	360	190	30

2.1.4 Urban Nonpoint Sources

Two types of pollutant sources in urban areas are considered: stormwater runoff going directly to a receiving water and combined sewer overflows (CSO). The first of these sources was considered in the development of the loading functions; the second was not. It is, therefore, necessary to outline a methodology for estimating loads from CSOs. After the approach has been given, estimates of pollutant loads from the urban areas in the Sandusky Basin will be presented.

2.1.4.1 Combined Sewer Overflows--Methodology

Most of the urban areas in the basin have combined sewers as a part of their collection systems. For many of these areas, combined sewers constitute a majority of the systems. In addition, for the majority of the wastewater treatment plants, the present average flow is near the design flow. Therefore, in the Sandusky Basin, CSOs (or bypasses) are common in many systems.

During dry weather flow (DWF), material settles to the bottom of a combined sewer. This material is scoured during periods of stormwater runoff. The scoured material, the stormwater, and sanitary sewage are lost during CSOs. The scoured material is quite significant in terms of pollutant loads; as will be shown below, the pollutant loads from sanitary sewage are probably rather small in comparison to the loads associated with scoured material.

Since many of the combined sewers overflow and bypasses appear to be common in the basin, large runoff events will remove most material settled in the sewers. Therefore, the annual load of pollutants for an urban area from CSOs (or bypasses) is given by:

$$\left\{\begin{array}{l}\text{pollutant}\\ \text{load}\end{array}\right\} = \left(\begin{array}{l}\text{pollutant}\\ \text{load in}\\ \text{stormwater}\end{array}\right) + \left(\begin{array}{l}\text{pollutant load}\\ \text{settled during}\\ \text{DWF and scoured}\\ \text{by high flow}\end{array}\right) + \left(\begin{array}{l}\text{pollutant load}\\ \text{associated with}\\ \text{loss of sanitary}\\ \text{sewage}\end{array}\right) \tag{1}$$

The settled load for the dry weather period will be assumed to be 10% of that associated with the DWF (Heaney et al., 1976). During the course of the year, all of this settled load will be assumed to be scoured by wet weather flow, and lost.

Table 2-16 shows the characteristics of "average" raw sewage. Based on an average per capita flow for an urban area (included nonresidential uses) of 150 gal. per capita per day, Table 2-16 also shows average annual per capita loads of various pollutants. The last column of the table shows average annual per capita pollutant loads assumed to be lost in CSOs due to scouring.

TABLE 2-16. ESTIMATION OF LOADS ASSOCIATED WITH SANITARY SEWAGE IN DRY WEATHER FLOW

Parameter	Average concentration (mg/L)	Annual per capita load based on 150 gpcd[a] flow (lb/yr)	10% of annual per capita load (lb/yr)
Suspended solids	200	91	9.1
BOD_5	200	91	9.1
Total nitrogen (as N)	40	18	1.8
Total phosphorus (as P)	10	4.7	0.47

[a] gpcd = gallons per capita per day.

The pollutant loads in stormwater will be estimated using curb loading rates for pollutants along with the assumption that the fraction of the stormwater transported by and lost from combined sewers during CSOs equals the fraction of the collection system that uses combined sewers.

The solids loading rate is assumed to account for all surface-related sources in the urban area. Therefore, the load per curb-mile includes inputs from nonstreet sources. The street loading rate is probably an underestimate of the total loading rate.

Loss of sanitary sewage during bypassing will be estimated as follows. It will be assumed that 70 bypasses per year occur and that each lasts 5 h. This is equal to the annual average (350 h/year) for many plants (EPA, 1976) and appears reasonable based on data for Bucyrus (Burgess and Niple, 1969). The portion of raw sewage lost during bypassing is related to the ratio of treatment plant capacity to average DWF. For a ratio of one, the loss is 67% (EPA, 1976). Since most plants in the Sandusky Basin have a ratio near one, 67% is used here. Bypassing for 350 h with a loss of 67% corresponds to 2.7% of annual DWF. Therefore, the pollutant load associated with loss of raw sewage will be estimated by:

$$\left\{\begin{array}{l}\text{pollutant load}\\ \text{associated with}\\ \text{loss of sanitary}\\ \text{sewage}\end{array}\right\} = 0.027 \left(\begin{array}{l}\text{annual per capita}\\ \text{load of pollutant}\\ \text{in DWF - from}\\ \text{Table 2-16}\end{array}\right) \left(\begin{array}{l}\text{population}\\ \text{served}\end{array}\right) \left(\begin{array}{l}\text{portion of}\\ \text{collection}\\ \text{system using}\\ \text{combined sewers}\end{array}\right) \quad (2)$$

The total load of pollutants lost during CSOs can then be found by combining the above results with Eq. (1):

$$\left\{\begin{array}{l}\text{annual}\\ \text{pollutant}\\ \text{load in}\\ \text{CSOs}\end{array}\right\} = \underbrace{fLl_s}_{\substack{\text{storm-}\\ \text{water}\\ \text{load}}} + f\ (\text{population}) \left(\begin{array}{l}\text{annual DWF}\\ \text{pollutant}\\ \text{load per}\\ \text{capita}\end{array}\right) (\underbrace{0.1}_{\substack{\text{load}\\ \text{scoured}}} \quad + \quad \underbrace{0.027}_{\substack{\text{raw}\\ \text{sewage}\\ \text{lost}}}) \quad (3)$$

$$= f\ (Ll_s + (0.127)\ (\text{population})\ (\text{annual DWF pollutant load per capita})$$

where f = fraction of system served by combined sewers
L = annual load of pollutant per curb-mile
l_s = number of curb-miles

The important assumptions that have been made are:

1. Ten percent of DWF pollutants settle in sewers.

2. All settled pollutants are scoured and lost during the course of a year.

3. The loss of sanitary sewage during overflows is 67% of DWF, and overflows occur 350 h/year.

4. It is implicitly assumed that all stormwater is discharged via separate or combined sewers.

The methodology just outlined will provide estimates of annual loads from CSOs. Estimation of loads on an event basis is more difficult. If event-related loads were required for screening purposes, the most likely approach would be to use average volumes of overflows and average pollutant concentrations during the overflow to estimate storm loads.

2.1.4.2 Character of the Urban Areas of the Sandusky River Basin

Table 2-17 presents a brief description of the urban areas within the basin. The table provides estimates of the population and street lengths for each area, the portion of the collection systems using combined sewers, and an indication of how close to capacity the basin's treatment plants are operating.

The largest cities in the basin are Bucyrus, Crestline, Fremont, Tifin, and Upper Sandusky (see Figure 2-1 for locations). These cities have a combined population of 69,000. For these cities, CSO-associated loads will be found using the procedure outlined in the preceding section. Carey is rather small, and since not all information needed is available, CSOs will be neglected and only direct stormwater runoff will be considered.

TABLE 2-17. SANDUSKY RIVER BASIN URBAN AREAS

City	Estimated population[a]	Estimated street miles[a]	Percent system having combined sewers[b]	For STP: avg. annual flow/design flow[b]
Carey	3,575	20	Part	0.61
Crestline	6,000	19	20%	0.93
Bucyrus	13,500	60	84%	1.11
Upper Sandusky	6,000	22	39%	1.00
Tiffin	23,000	67	60%	0.80
Fremont	20,500	75	90%	0.73

[a] Source: City officials.

[b] Source: Ohio EPA, "State Water Quality Management Plan, Sandusky River Basin," Part II, no date, preliminary report.

In all calculations, none of the stormwater runoff will be assumed to be treated. It is assumed that all stormwater runoff enters a body of water directly.

Table 2-18 characterizes the street loading rates for the City of Bucyrus. Since these values are undoubtedly more typical of the Sandusky Basin than the average loading rates given in the loading functions report (McElroy et al., 1976) they are used here. It is worth noting, however, that the solids loading rate in Table 2-18 is about 2.4 times the "average" given in the loading functions report for the northeast region. The loading rates for the other contaminants are smaller than the average values.

2.1.4.3 Load Estimation

Table 2-19 presents estimates of annual loads from CSOs for the urban areas; Table 2-20 gives estimates for loads in stormwater but not in CSOs; and Table 2-21 presents the sum of the two. Results in Table 2-19 were obtained using Eq.(3) and results in Table 2-20 were found using the standard screening approach, load = $(1-f)Ll_s$.

TABLE 2-18. STREET LOADING RATES FOR BUCYRUS[a]

Parameter	Loading rates lb/curb-mile/day	Loading rates tons/curb-mile/year
Total solids[b]	690	126
BOD_5	1.4	0.26
Total nitrogen (as N)	0.61	0.11
Total phosphorus (as P)	0.04	0.007

a Source: Sartor, J. D., and G. B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081, November 1972. p. 142.

b Source: A particle size distribution was given by Sartor and Boyd (p. 4E); 26% of the solids are classified as silt, and 74% are classified as sand (above 43 μm in size).

TABLE 2-19. ESTIMATED ANNUAL LOADS FROM COMBINED SEWER OVERFLOWS

City	Pollutant loads (tons/year) Suspended solids	BOD_5	N_T	P_T
Bucyrus	3,400	92	24	4
Carey	0	0	0	0
Crestline	260	10	2	0.5
Fremont	4,500	142	37	6
Tiffin	2,700	101	25	5
Upper Sandusky	580	18	5	0.8

TABLE 2-20. ESTIMATED ANNUAL LOADS IN STORMWATER RUNOFF, NOT IN CSOs

City	Pollutant loads (tons/year)			
	Suspended solids	BOD_5	N_T	P_T
Bucyrus	620	5	2	0.1
Carey	1,300	10	4	0.3
Crestline	990	8	3	0.2
Fremont	490	4	2	0.1
Tiffin	1,800	14	6	0.4
Upper Sandusky	880	7	3	0.2

TABLE 2-21. ESTIMATED TOTAL ANNUAL URBAN LOADS

City	Pollutant loads (tons/year)			
	Suspended solids	BOD_5	N_T	P_T
Bucyrus	4,000	97	26	4
Carey	1,300	10	4	0.3
Crestline	1,300	18	5	0.7
Fremont	5,000	146	39	6
Tiffin	4,500	115	31	5
Upper Sandusky	1,500	25	8	1

The suspended solids in the portion of the load associated with the runoff from street surfaces were determined based on the assumption that only the silt portion of the solids was transported in suspension. The larger particles are unlikely to stay in suspension and cannot be compared directly with the suspended solids load in sanitary sewage. The size distribution of the solids for Bucyrus was used for all the cities, i.e., 26% of the solids were assumed to be suspended. All the BOD, N, and P loads were assumed to be delivered to a receiving water.

Data are available for pollutant loads in CSOs for Bucyrus for 1969. Table 2-22 compares values for annual loads estimated from measurements made in the city with those estimated here. As Table 2-22 shows, the agreement between "measured" and estimated values is rather good for BOD_5, N_T, and P_T, especially considering the character of the screening methodology used. The table also shows that the methodology appears to overpredict the solids loading.

The assumption concerning the high frequency of CSOs in the basin can be viewed in the following light. Assume that an urban area of 500 acres contributes 0.1 in. of runoff to the combined sewers. That volume is 1.38×10^6 gal. If this runs off in 12 h, the flow is 2.7 MGD,* on average. Such numbers are not unreasonable for a modest storm in any of the areas. This flow may be compared to the unused capacity of the region's wastewater treatment plants. Table 2-23 shows estimated unused capacities of the plants. The portion of the system that would contribute to overflows (percent combined sewers) is also shown. Note that 2.7 MGD is well above any of the capacities available. Therefore, overflows or bypasses should be common in all the cities.

To illustrate the relative importance of the various sources of pollutants to the CSO load estimates, Table 2-24 shows the contribution of each source for the pollutants considered for Bucyrus.

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* MGD = million gallons per day.

TABLE 2-22. COMPARISON OF LOAD ESTIMATES FOR BUCYRUS

Parameter	Loads: Estimate based on observations of CSOs in Bucyrus in 1969[a]	Loads: Estimate for CSOs based on loading rates
Annual volume of CSOs (MG)	350	-
Suspended solids (T/yr)	700	3,400
BOD_5 (T/yr)	175	92
N_T (T/yr)	19[b]	24
P_T (T/yr)	4.9	4

[a] Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows," FWQA, 1969.

[b] Based on average flow concentrations given in the Burgess and Niple report.

TABLE 2-23. AVERAGE UNUSED CAPACITY OF PLANTS DURING DRY FLOW PERIOD

City	Average flow (MGD)	Average flow/ capacity	Capacity (MGD)	Unused capacity (MGD)	Percent combined sewers
Bucyrus	1.9	1.11	~ 1.9	0	84
Crestline	0.56	0.93	0.6	0.04	19
Fremont	5.1	0.8	6.4	1.3	90
Tiffin	2.7	0.73	3.7	1.0	60
Upper Sandusky	1.7	1.0	~ 1.7	0	39

TABLE 2-24. COMPONENTS OF COMBINED SEWER OVERFLOW LOADS FOR BUCYRUS

	Loads (tons/yr)			
Parameter	Scoured material	Stormwater	Sanitary sewage lost	Total
Suspended solids	52	3,300	14	3,400
BOD_5	52	26	14	92
N_T	10	11	3	24
P_T	2.7	0.7	0.7	4

As the table shows, stormwater dominates the suspended solids load; the scoured material is most important for BOD and P; and stormwater and scoured material both contribute substantially to the nitrogen load. The loss of sanitary sewage is a relatively minor addition in all cases.

The sensitivity of the results to the assumptions used in the analysis can be inferred from Table 2-24:

1. Since loss of sanitary sewage is a fairly minor component of the load, the overall results are not sensitive to any of the assumptions made concerning this source.

2. Since the stormwater component provides essentially 100% of the suspended solids load, the solids loading rate and the portion of the solids assumed to be suspended are critical factors in the analysis.

3. The nitrogen load obtained is sensitive to the nitrogen loading rate used to estimate stormwater load and to the assumptions related to the settling and later scouring of DWF pollutants. Fifty percent changes in the loading rates or the settling/scouring portion of DWF pollutants produce about a 20% change in the total load (for Bucyrus).

4. Since the input of scoured material appears to be the most important source of phosphorus and BOD, the estimate of loads of these materials is sensitive to the quantity of DWF pollutants which settle and are scoured. A 50% variation in this quantity would change P_T and BOD loads for Bucyrus by about 30%.

Finally, it is interesting to compare the results obtained using measured street loading rates for Bucyrus with those obtained using average rates for the region as given in the screening methodology. For the Northeast, the average solids loading rate is 291 lb/day/curb-mile. Based on the average pollutant concentrations for the region, the loading rates for BOD_5, total N, and total P are 5.8, 2.4, and 0.28 lb/day/curb-mile, respectively. Using these values for Bucyrus gives the results shown in Table 2-25.

As Table 2-25 indicates, using average rather than measured loading rates results in improved estimates for suspended solids and BOD_5 (compared to measured loads in CSOs) and poorer results for N and P. The suspended solids calculation assumed the same fraction of silt for both calculations and is based on measurements made in Bucyrus. It can be concluded that, for the four parameters studied, using average values for loading gives results as good as those using local rates. Therefore, using regional values in this case provides rather accurate results. However, two factors should be kept in mind. First, the suspended solids load calculation used information on the particle size distribution obtained for measurements in Bucyrus. Such size distribution information will not normally be available in the application of the methodology. Second, although it appears in this case that average values provide results as good as measured local values for loading rates, it would seem wisest to always use local information when available. Nevertheless, the fact that the average values provide reasonable results increases their credibility.

TABLE 2-25. COMPARISON OF CSO LOADS FOR BUCYRUS

Parameter	Load based on observations in Bucyrus in 1969[a]	Load based on measured street loading rates for Bucyrus	Load based on average street loading rates for region
Suspended solids (T/yr)	700	3,400	1,500
BOD_5 (T/yr)	175	92	170
N_T (T/yr)	19	24	56
P_T (T/yr)	4.9	4	8.3

[a] Source: Bucyrus and Niple, Ltd., "Steam Pollution and Abatement from Combined Sewer Overflows" (FWQA, 1969).

2.1.5 Nonpoint Source Impacts on Water Quality

Estimates of instream concentrations of sediment, phosphorus, and nitrogen, based on the loading rates estimated in the preceding sections, are given in sections 3.2.9 and 3.2.10 of Volume II of this report. Calculation of instream concentrations of these constituents provides the best means available for verifying the nonpoint load estimation procedures. The results presented in Volume II indicated that the loading estimates obtained for sediment and phosphorus for this basin appear reasonable.

2.2 DEMONSTRATION EXAMPLE: THE CHESTER RIVER BASIN

2.2.1 Character of the Basin

The Chester River is located in the Delmarva Peninsula onthe eastern shore of Chesapeake Bay. The headwaters are in Delaware, but most of the basin is located in Kent and Queen Annes Counties in Maryland. The area of the basin is approximately 440 sq miles. The major land use is agriculture, and corn and soybeans are the major crops. Some small grains (wheat and barley) are also grown.

The relief of the basin is low. The uplands have elevations of 80 to 100 ft, and the lower basin elevation ranges from sea level to about 60 ft. Average annual precipitation in the basin is about 43 in., and is fairly uniformly distributed throughout the year. Normally, the wettest month is August (4.9 in.) and the driest month is February (2.9 in.).

For purposes of analysis, the Chester River Basin has been divided into six subbasins as indicated in Figure 2-2 and Table 2-26. The numerical designation of the basins corresponds to those defined by the Maryland Department of Natural Resources (DNR). The Maryland DNR includes the Wye River Basin (to the south) as part of the Chester River Basin, and the designations 1 to 4 are subbasins of the Wye. The Wye River Basin was not included in any analysis of the Chester River Basin.

TABLE 2-26. CHESTER RIVER SUBBASINS

Subbasin	Area (acres)	Length of principal streams (miles)
5 Chester River	40,943	27
6 Langford Creek	24,878	32
7 Corsica River	24,511	31
8 Southwest Creek	34,517	39
9 Chester River	35,527	8
10 Chester River	114,207	63
Total	274,583	

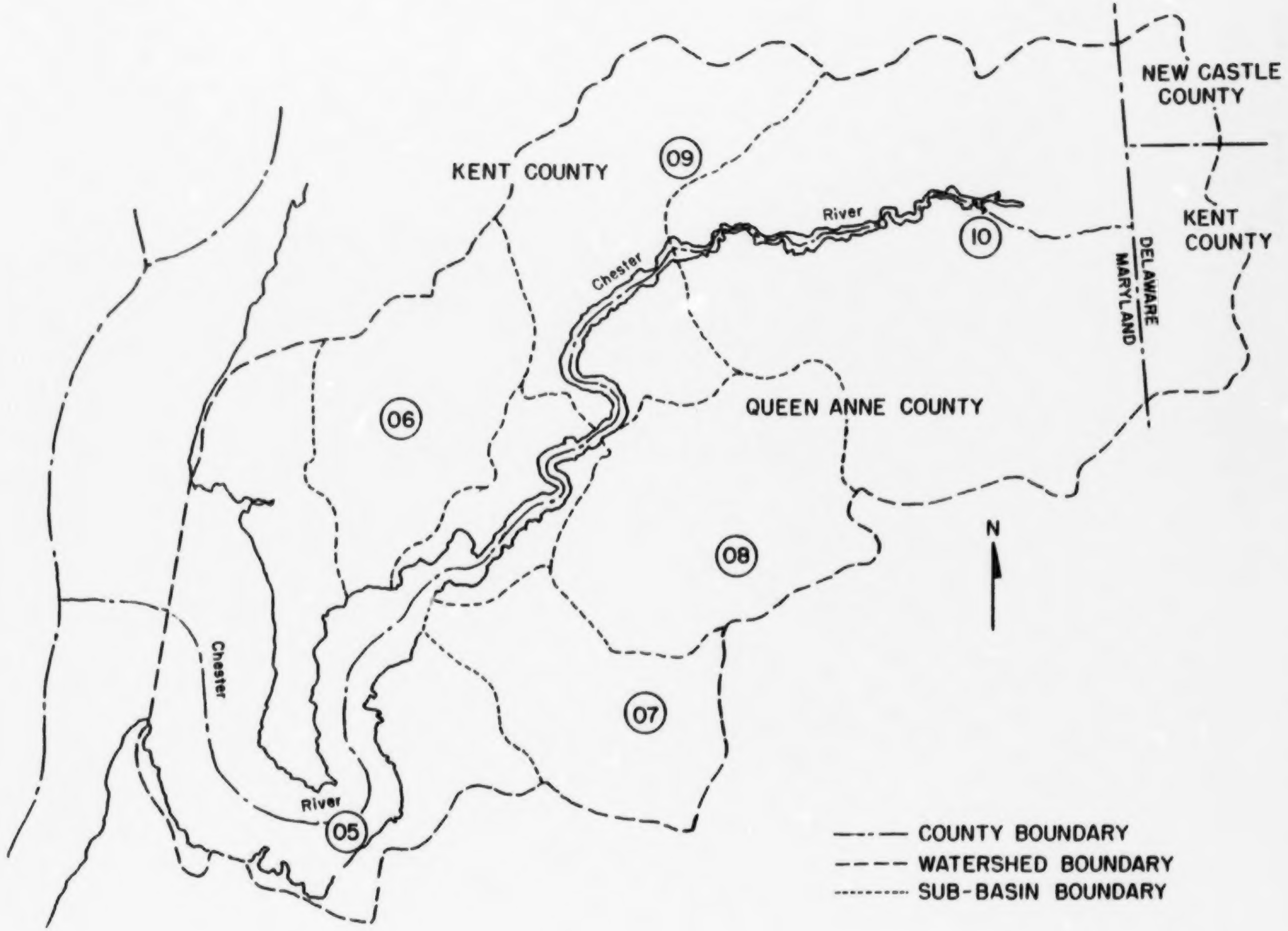
NEW CASTLE COUNTY
KENT COUNTY
DELAWARE
MARYLAND
KENT COUNTY
09
River
10
Chester
QUEEN ANNE COUNTY
06
N
08
Chester
07
River
05
COUNTY BOUNDARY
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY

Figure 2-2. Chester River Basin and Subbasins.

2.2.2 Nonpoint Load Estimation Methodology - An Overview

The procedure used for the Chester River Basin is essentially the same as that used for the Sandusky. The details of the approach are not repeated here. Since the Chester River Basin does not contain any significant sources of urban runoff, urban nonpoint sources are not considered.

2.2.3 Rural Nonpoint Sources

2.2.3.1 Parameter Evaluation

2.2.3.1.1 Rainfall Factor

No recording rain gauges are located in the Chester River Basin. The nearest such gauges are located 25 to 30 miles away at Wilmington, Delaware, Perry Point, Maryland (near the mouth of the Susquehanna), Baltimore, Maryland, and Federalsburg, Maryland. There are four nonrecording gauges in the basin. Since rainfall records with at least 30-min time resolution are needed to estimate R, it was necessary to use one of the stations outside the basin for the analysis. However, use of a distant station reduces the accuracy of the results.

Table 2-27 shows the periods analyzed (selected for compatibility with the study presented in Volume II) and the results for Wilmington. Wilmington was chosen arbitrarily for use in the study; the other stations mentioned above would have served equally well. The results in Table 2-27 were obtained using data obtained from the National Climatic Center in Asheville, North Carolina.

For the 14 periods analyzed, the average value of EI_{30} is 14.6, or 11.4 without the largest single value of EI_{30}. The periods studied are distributed throughout April to September, with half occurring in July and August. The periods are usually 1 to 2 days long and precede selected 7-day high flow periods for the Chester. Occasionally, additional small amounts of rainfall occurred later in the 7-day period, but this rainfall was neglected.

TABLE 2-27. EVALUATION OF EI_{30} FOR THE CHESTER BASIN

	Total rainfall at Wilmington (in.)	EI_{30} for Wilmington
June 18-19, 1967	1.55	8.3
August 3-4, 1967	2.94	56.0
August 24-25, 1967	1.00	3.1
July 27-29, 1969	3.71	22.9
August 9, 1969	0.56	2.2
April 14-15, 1970	2.26	8.0
April 20, 1970	0.82	2.3
September 11-13, 1971	4.92	37.2
June 22-27, 1972	Hurricane Agnes - neglected	
July 13, 1972	0.94	3.6
June 2, 1974	0.32	0.25
July 13, 1975	2.61	30.0
July 20, 1975	1.12	12.2
September 22-24, 1975	3.77	13.7
May 8-9, 1978	1.30	4.2
Total	27.9	204.0

Total rainfall at Wilmington for the events analyzed was 27.9 in., while the total rainfall at Chesterton (in the Chester Basin) for the same period was about 38 in. The correlation coefficient of the rainfall (in each period) at Wilmington and Chesterton for the 14 events is 0.62. For Chester and Millington (also in the basin) the correlation coefficient (11 events) is 0.85, and for Wilmington and Millington the correlation coefficient (11 events) is 0.80.

The average annual value for R for the Chester Basin is in the range 190 to 200. An average storm with an EI equal to 14.6 produces about 7% of the annual soil loss. An EI value of 14.6 has been used in the analysis.

2.2.3.1.2 Soil Erodibility Factor (K)

The weighted soil erodibility (K) factors for the Chester River Basin were established from soil association maps from the State of Maryland and from published soil surveys of the counties in the basin. The K factors by county and subbasin are shown in Table 2-28. In this analysis, the weighted average K was assumed to represent all the soils within the fraction of a subbasin within a county.

TABLE 2-28. AVERAGE K FACTOR VALUES BY SUBBASIN AND COUNTY FOR THE CHESTER RIVER

	K values by county			
Subbasin	Kent, Md.	Queen Annes, Md.	Kent, Del.	New Castle, Del.
5	0.40	0.36	-	-
6	0.38	-	-	-
7	-	0.34	-	-
8	-	0.32	-	-
9	0.35	0.28	-	-
10	0.36	0.30	0.28	0.30

GR14CC(e)

2.2.3.1.3 Slope Factors (L and S)

Slopes and slope lengths were obtained from the data based used for the nonpoint calculator. These factors have been established for each land capability class within each Land Resource Area (LRA). The Chester River Basin is contained within two LRAs, LRA 149 (Northern Coastal Plain) and LRA 153 (Atlantic Coast Flatwoods). Values for the LS factor were calculated based on these slopes and slope lengths. The slopes and slope lengths are tabulated in Appendix I.

2.2.3.1.4 Cover Factor (C)

Cover factors are dependent on the cropping patterns of the basin or subbasin under study. Since cropland is the primary source of sediment, crop acreages and cropping rotation for a given year must be known. State agricultural statistics were used to establish crop acreages in each county, and county extension agents provided information on cropping rotations. Uniform distribution of crop acreage and rotation within each county was assumed.

The analysis of agricultural practices in the Chester River Basin was done for the year 1973. This year was chosen because it was a typical recent year, i.e., rainfall and crop yield were approximately normal. The acreages of principal crops for 1973 are shown in Table 2-29. Acreages of crops within various crop rotations were determined from contacts with county agents. Cover factors for each crop throughout the growing season were determined in the same manner as described in detail for the Sandusky River Basin in Section 2.1.3.1.4 of this volume.

The cropping patterns in the Chester River Basin are:

1. All small grain is in rotation with corn and soybeans.
2. No meadow is in rotation.
3. No winter cover crop; stubble is left on the field.
4. Some corn and soybeans are in continuous production.

There are four major cropping rotations for corn, soybeans, and small grain (wheat and barley). These practices are:

1. Four-year rotation of corn-corn-small grain-soybeans = 4 x acres in small grain. This practice is used in Kent County, and Queen Annes County, Maryland; and Kent County, Delaware.

TABLE 2-29. AGRICULTURAL DATA FOR COUNTIES IN THE CHESTER RIVER BASIN FOR 1973

County	Crop area (10^3 acres)				
	Corn	Soybeans	Wheat	Barley	Total
Kent, Md.	50.0	29.0	8.5	4.0	91.5
Queen Annes, Md.	55.0	38.0	13.3	5.8	112.1
Kent, Del.	52.0	65.0	11.0	8.5	136.5
New Castle, Del.	23.0	30.0	10.0	4.5	67.5

County	Areas in rotation (10^3 acres)			
	CCSgSb	CC	SbSb	CSgSb
Kent, Md.	50.0	25.0	16.5	-
Queen Annes, Md.	76.4	16.8	18.9	-
Kent, Del.	78.0	13.0	45.5	-
New Castle, Del.	-	8.5	15.5	43.5

CCSgSb = Corn-corn-small grain-soybean (4-yr rotation).
CC = Continuous corn.
SbSb = Continuous soybean.
CSgSb = Rotation corn-small grain-soybean (3-yr rotation).

2. Three-year rotation of corn-small grain-soybeans = 3 x areas in small grain; used for New Castle County, Delaware.

3. Continuous corn = area in corn minus (2 x area in small grain) for 4-year rotation corn-corn-small grain-soybeans; or = area in corn minus area in small grains for 3-year rotation in corn-small grain-soybeans.

4. Continuous soybeans = area in soybeans minus area in small grain for all rotations.

The acreages for those cropping practices are also shown in Table 2-29.

From the agronomic (growth stage, cropping practice) data describing each crop, it is possible to determine C factors for corn, soybeans, and small grains at specific times of the year. The methods used are described in Section 2.1.3.1.4 of this report. Since the nonpoint loads are generated by rainfall events, a series of time intervals were developed using the periods in Table 2-27 and the C factors for these time intervals. These C factors are given in Table 2-30.

TABLE 2-30. COVER FACTORS FOR VARIOUS INTERVALS FOR THE CHESTER RIVER BASIN

Interval	Crop			
	Corn[a]	Corn[b]	Soybeans	Small Grains
Mid-April-early May	0.29	0.39	0.18	0.16
Early May-late May	0.29	0.39	0.18	0.09
Late May-late June	0.26	0.34	0.25	0.06
Late June-late August	0.21	0.26	0.19	0.07
Late August-mid-October	0.18	0.22	0.14	0.07

[a] Kent, Maryland; Queen Annes, Maryland; and Kent, Delaware.

[b] New Castle, Delaware.

When the C factors were evaluated, it was noted that the values for corn in New Castle County, Delaware, were significantly different from those for the other counties in the basin. Therefore, corn grown in New Castle County was assigned a separate C value.

2.2.3.1.5 Support Practice Factor (P)

Lacking needed information on current conditions, it was assumed that no significant changes occurred in the cropping practice factor (P) between 1967 and 1979. Therefore, P factors based on the 1967 Conservation Needs Inventory (CNI) were used for the Chester River Basin. These values are tabulated in Appendix I.

2.2.3.1.6 Land Use Within the Chester River Basin

Land use changes have occurred in the basin; from 1967 to 1973 there was an increase in the acreage of corn and soybeans and a reduction in the acreage of small grains and pasture. Crop acreages in the 1967 CNI were shifted to reflect the acreages reported in the agricultural statistics of 1973, the base year for the analysis. The approach used followed that described for the Sandusky.

Specifically the following changes were made:

Kent County, Maryland: 15,700 acres of corn were shifted to soybeans; 6,300 acres of small grain were shifted to soybeans; and 7,600 acres of small grain were shifted to pasture.

Queen Annes County, Maryland: 10,000 acres of corn were shifted to beans; 3,800 acres of corn were shifted to pasture; 4,000 acres of small grains were shifted to soybeans; and 4,400 acres of small grain were shifted to pasture.

Kent County, Delaware: 15,270 acres of corn were shifted to pasture; and 1,755 acres of corn were shifted to small grain.

New Castle County, Delaware: 1,700 acres of small grain were shifted to soybeans; 8,700 acres of corn were shifted to beans; and 1,900 acres of "Conservation Use Only" were shifted to beans.

2.2.3.1.7 Nutrients

Soil nutrient concentrations were obtained for each county in the basin from soil scientists in the area and from soil test results where possible. In most cases, only values for available phosphorus and nitrogen could be obtained. Total phosphorus was estimated to be in the range of 100 to 200 ppm based on regional soil data. This range represents total phosphorus content of virgin soils. Total phosphorus content of agricultural soils is probably higher due to fertilizers. We used a value of 200 ppm for total phosphorus concentration. Since nitrogen is required in the total form for purposes of load estimation, the Jenny equation was used to estimate total soil nitrogen levels. The values for available soil phosphorus and total soil nitrogen for the counties in the Chester River Basin are shown in Table 2-31.

TABLE 2-31. SOIL NUTRIENT CONCENTRATIONS IN THE CHESTER RIVER BASIN

County	Average nutrient concentration in soil (ppm)	
	Available phosphorus [a]	Total nitrogen [b]
Kent, Md.	24	1,550
Queen Annes, Md.	25	1,200
Kent, Del.	25	1,590
New Castle, Del.	24	1,630

[a] Total phosphorus is approximately 200 ppm.

[b] Available nitrogen is assumed to be 10% of total.

Enrichment ratios for the nutrients in soils were evaluated using the method described for the Sandusky Basin. The value obtained for the Chester River Basin is 1.97 ± 0.11; a value of 2.0 was used for making the load estimates.

Finally, nitrogen in rainfall was estimated to be 0.0045 lb/acre/event using the methods described in Section 2.1.3.1.7.

2.2.3.1.8. Sediment Delivery Ratio

There are no regular, long-term measurements of sediment discharge in the Chester Basin. Discussions with the Soil Conservation Service and the United States Geology Survey (USGS) did not reveal any information on sediment yields in the basin or any evidence of the existence of regression relationships for predicting sediment yield based on watershed variables. There is, therefore, no dependable method available for determining sediment delivery ratios in the basin. Gross soil loss was determined and loads found using a delivery ratio of 100%. The Chester Basin has an area of 440 sq miles and is very flat. It would be expected that the annual delivery ratio for such a basin would be low, probably below 10%. A delivery ratio of 0.1 (10%) was used for the analysis in Volume II.

Steambank and gully erosion have been neglected in the analysis. In portions of the basin shoreline erosion is a serious problem. The sediment loads determined in this report underestimate the total sediment load in the basin to the extent that such other sources were neglected.

2.2.3.2. Load Determination

The nonpoint loads determined for the Chester River Basin are presented in Table 2-32.

TABLE 2-32. ESTIMATED STREAM LOADING RATES FOR THE AVERAGE CHESTER EVENT, SEDIMENT DELIVERY RATIO = 0.1

	ton/mile/event	lb/mile/event				
		Phosphorus			Nitrogen	
Subbasin	Sediment	Total	Available	BOD_5	Total	Available
5	46	36	4.5	490	250	32
6	27	21	2.7	310	160	19
7	17	13	1.6	170	90	13
8	18	14	1.7	190	100	14
9	130	102	12.8	1,620	820	102
10	42	33	4.1	510	260	33

2.2.4 Nonpoint Source Impacts on Water Quality

Instream concentration estimates for sediment, nitrogen, phosphorus, and BOD_5 for the Chester River are presented in Section 3.3.6.2 of Volume II. Since point source loads appear to be of minor importance in the basin, the nonpoint loads estimated in the preceding section are the primary pollutant inputs for the basin.

2.3 DEMONSTRATION EXAMPLE: PATUXENT RIVER BASIN

2.3.1 Character of the Basin

The Patuxent River is located in Maryland between Washington, D.C., and Baltimore and drains into the western side of Chesapeake Bay. The drainage basin area covers about 930 sq miles. Approximately half of the basin is forested, 35% is agriculture, and the remainder is suburban. Principal crops of the basin are corn, soybeans, tobacco, and small grains.

The headwaters of the Patuxent area are in the Piedmont region (Howard and Montgomery counties), and the river flows through the Atlantic Coastal Plain (Anne Arundel, Calvert, Charles, Prince Georges, and St. Marys counties).

Average precipitation throughout the basin is about 43 in. annually, with about 25% of the annual total coming in July and August. The driest months are December and February.

The Patuxent River Basin has been divided into subbasins (Figure 2-3) as defined by the State of Maryland. The acreages of the subbasins and lengths of principal streams are shown in Table 2-33.

TABLE 2-33. PATUXENT RIVER SUBBASINS

Subbasin	Area (acres)	Length of principal streams (miles)
1	197,738	121
2	67,106	34
3	70,594	59
4	47,552	22
5	66,463	61
6	35,894	22
7	36,169	28
8	49,480	49
Total	570,996	

2.3.2 Nonpoint Load Estimation Methodology--An Overview

The procedure used for nonpoint load estimation for the Patuxent River Basin is essentially the same as that used for the Sandusky. The details of the apporach are not repeated. Both urban and rural nonpoint sources are considered in the basin.

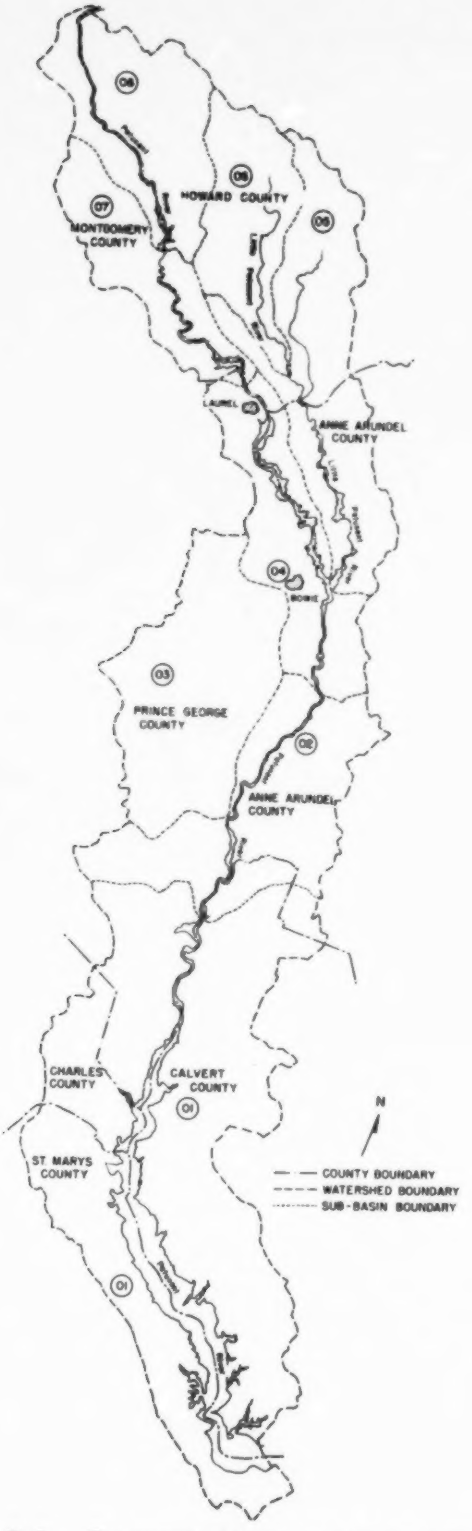
08
06
HOWARD COUNTY
05
07
MONTGOMERY COUNTY
LAUREL
ANNE ARUNDEL COUNTY
04
BOWIE
03
PRINCE GEORGE COUNTY
02
ANNE ARUNDEL COUNTY
CHARLES COUNTY
CALVERT COUNTY
01
ST. MARYS COUNTY
01
N
COUNTY BOUNDARY
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY

Figure 2-3. Patuxent River Basin and Subbasins.

2.3.3 Rural Nonpoint Sources

2.3.3.1 Parameter Evaluation

2.3.3.1.1 Rainfall Factor (R)

There are several recording rain gauges near the basin in Beltsville, Unionville, Baltimore, and Leonardtown. Beltsville is the most centrally located of the gauges and was used in the analysis.

Table 2-34 shows the periods analyzed (selected for compatibility with the study presented in Volume II) and the results for Beltsville. Data for Beltsville were obtained from the National Climatic Center.

For the 16 periods with data the average value of EI_{30} is 22.2 (average annual value is about 220); without the two largest events, the average is 14.8. The events are distributed through the period April to September; about half occurred in April and May.

An attempt was made to determine the uniformity of rainfall over the basin by comparing rainfall totals for Beltsville with those at Leonardtown. For the periods studied, there are 10 intervals having data at both stations. The average rainfall event at Beltsville was about 2 in., while Leonardtown had about 1.5 in. No attempt was made to adjust for any nonuniformity in rainfall over the basin.

2.3.3.1.2 Soil Erodibility Factor (K)

The soil association maps and soil surveys for the Patuxent River Basin were analyzed to determine weighted averages of K factors for the soil loss continuation. The resulting K factors for subbasin within specific counties of the basin are presented in Table 2-35.

TABLE 2-34. EVALUATION OF EI_{30} FOR THE PATUXENT BASIN

	Total rainfall at Beltsville[a] (in.)	EI_{30} for Beltsville
May 6-7, 1967	1.45	3.7
August 23-25, 1967	4.63	75.3
May 27-28, 1968	2.22	6.5
June 27-July 3, 1968	2.65	22.4
April 14-15, 1970	2.6	4.2
May 14-20, 1970		No data
July 9-10, 1970	2.94	56.3
July 20-23, 1970	1.07	1.0
April 6-7, 1971	1.80	2.0
May 13-16, 1971	3.55	16.8
May 28-June 3, 1971	2.15	6.3
July 1, 1971	1.1	11.2
August 2-4, 1971	2.01	46.1
September 11-12, 1971	3.05	73.2
April 1-2, 1973	2.1	18.5
April 25-27, 1973	2.7	9.5
May 27-28, 1973	1.0	2.8
September 23-29, 1975		Data problems
April 1-7, 1976		Data problems
April 5-11, 1977		Data problems
May 14-20, 1978		Data problems

---

[a] Data prior to April 1973 are from the Beltsville Plant Station 5. Those after that date are from Beltsville. Generally, the difference between the two locations seems small.

TABLE 2-35. AVERAGE K FACTOR VALUES BY SUBBASIN FOR THE PATUXENT BASIN

Subbasin	Average K values by county						
	Anne Arundel	Calvert	Charles	Howard	Montgomery	Prince Georges	St. Marys
1	0.37	0.34	0.38	-	-	0.33	0.31
2	0.34	0.33	-	-	-	0.34	-
3	-	-	-	-	-	0.33	-
4	0.34	-	-	0.37	-	0.34	-
5	0.32	-	-	0.35	-	-	-
6	-	-	-	0.36	-	-	-
7	-	-	-	0.36	0.37	-	-
8	-	-	-	0.35	0.37	-	-

2.3.3.1.3 Slope Factors (L and S)

Slopes and slope lengths for the IRAs of which the Patuxent River Basin is a part were obtained from the national data base associated with the nonpoint calculator. These values were used to obtain slope and slope length factors for the basin. The data used included that for LRA 148 (Northern Piedmont) and LRA 149 (Northern Coastal Plains) and are tabulated in Appendix I.

2.3.3.1.4 Over Factor (C)

The year 1973 was chosen as the base year for defining land use conditions for the Patuxent River Basin. The areas of principal crops for that year are presented in Table 2-36.

TABLE 2-36. AGRICULTURAL DATA FOR COUNTIES IN PATUXENT RIVER BASIN IN 1973

County	Crop area (10^3 acres)					Total
	Corn	Wheat	Tobacco	Soybeans	Barley	
Anne Arundel	9.0	0.8	4.6	2.0	0.1	16.5
Calvert	7.0	0.8	4.5	1.5	0.4	14.2
Charles	11.0	2.5	5.5	5.0	0.2	24.2
Howard	14.0	2.5	-	-	3.0	19.5
Montgomery	21.0	5.7	-	0.7	3.0	30.4
Prince Georges	8.0	2.2	4.2	3.0	0.1	17.5
St. Marys	13.0	3.1	6.2	9.5	1.6	33.4

Conversations with county agents indicated the following cropping patterns:

1. Continuous corn.
2. Continuous tobacco with a winter cover crop.
3. Corn-soybeans in 2-year rotation.

4. Corn-small grains (wheat, barley) in 2-year rotation.
5. Tobacco-tobacco-cover (rye) in 3-year rotation.
6. Small grain-cover in an annual rotation.
7. Corn-corn-small grain-small grain in 4-year rotation.
8. Corn-corn-cover-corn in 4-year rotation.

These patterns were used in conjunction with 1973 agricultural statistics to estimate acreages of crops grown in the rotations. The results of this analysis are presented in Table 2-37.

TABLE 2-37. ESTIMATED AREAS OF PRINCIPAL CROP ROTATIONS BY COUNTY IN PATUXENT RIVER BASIN IN 1973

	Crop area (10^3 acres)							
County	CC	TcT	CSb	CSg	CCCoCo	TTCo	SbCo	CCSgSg
Anne Arundel	6.1	4.6	4.0	1.8	-	-	-	-
Calvert	4.3	4.5	3.0	2.4	-	-	-	-
Charles	3.3	-	10.0	5.9	-	5.5	-	-
Howard	14.0	-	-	-	-	-	5.5	-
Montgomery	-	-	1.4	-	11.6	-	-	17.4
Prince Georges	2.7	-	6.0	4.6	-	4.2	-	-
St. Marys	-	5.0	19.0	7.0	-	2.4	-	-

CC = Continuous corn.
TcT = Tobacco-winter cover-tobacco (annual rotation).
CSb = Corn-soybean (2-yr rotation).
CSg = Corn-small grain (2-yr rotation).
CCCoCo = Corn-corn-cover-cover (4-yr rotation).
TTCo = Tobacco-tobacco-Cover crops (3-yr rotation).
SbCo = Soybeans-cover crops (annual rotation).
CCSgSg = Corn-corn-small grain-small grain (4-yr rotation).

The C factors for the various crops and rotations were developed for each of the counties within the basin. These factors were then matched with rainfall intervals established using the periods given in Table 2-34. In doing so, it was found that significant variations in C factor occurred from county to county within the basin. Therefore, each crop in each county was assigned a C value for each rainfall interval. These C factors are given in Table 2-38.

2.3.3.1.5 Support Practice Factor (P)

The 1967 CNI contains information pertaining to land on which conservation practices have been applied. Lacking more current information, it was assumed that conservation practices did not change significantly between 1967 and 1973. The P values used are tabulated in Appendix I.

2.3.3.1.6 Land Use Within the Patuxent River Basin

The changes in cropping patterns as reflected in differences between the 1967 CNI and the 1973 base year were accommodated by shifting acreages within the various counties. Specific changes were:

Anne Arundel County: 1,490 acres of row crops (soybeans or tobacco) were shifted to corn; 5,960 acres of row crops and small grains were shifted to pasture.

Calvert County: 3,170 acres of row crops were shifted to corn; 13,400 acres of row crops and small grains were shifted to pasture.

Charles County: 560 acres of small grains were shifted to corn; 200 acres of small grains were shifted to row crops; and 2,140 acres of small grains were shifted to pasture.

Howard County: 880 acres of row crops were shifted to corn; 1,930 acres of row crops and small grains were shifted to pasture.

Montgomery County: 1,500 acres of corn were shifted to row crops; 1,000 acres of corn were shifted to small grains; 4,800 acres of pasture were shifted to small grains.

TABLE 2-38. COVER FACTORS (C) FOR CROPS BY RAINFALL INTERVALS AND COUNTIES FOR THE PATUXENT RIVER BASIN

Rainfall interval/county	C factor for crop				
	Corn	Small grain	Tobacco	Soybeans	Row crops
1. Early April-mid-April					
Anne Arundel	0.14	0.19	0.02	-	0.04
Calvert	0.14	0.19	0.02	-	0.03
Charles	0.21	0.19	0.02	-	0.04
Howard	0.07	0.16	-	0.07	-
Montgomery	0.06	0.16	-	0.07	-
Prince Georges	0.18	0.19	0.05	-	0.06
St. Marys	0.80	0.21	0.02	-	0.05
2. Mid-April-late May					
Anne Arundel	0.68	0.14	0.26	-	0.20
Calvert	0.68	0.14	0.26	-	0.21
Charles	0.73	0.14	0.26	-	0.17
Howard	0.60	0.12	-	0.07	-
Montgomery	0.52	0.12	-	0.07	-
Prince Georges	0.71	0.14	0.46	-	0.30
St. Marys	0.78	0.16	0.17	-	0.11
3. Late May-late June					
Anne Arundel	0.59	0.09	0.30	-	0.41
Calvert	0.19	0.09	0.30	-	0.39
Charles	0.62	0.09	0.30	-	0.47
Howard	0.52	0.09	-	0.66	-
Montgomery	0.45	0.09	-	0.66	-
Prince Georges	0.61	0.09	0.51	-	0.57
St. Marys	0.66	0.09	0.20	-	0.40
4. Late June-late July					
Anne Arundel	0.45	0.03	0.25	-	0.35
Calvert	0.45	0.07	0.25	-	0.33
Charles	0.48	0.03	0.25	-	0.41
Howard	0.41	0.03	-	0.58	-
Montgomery	0.36	0.03	-	0.58	-
Prince Georges	0.47	0.03	0.38	-	0.46
St. Marys	0.51	0.03	0.17	-	0.42

TABLE 2-38. (continued)

Rainfall interval/county	C factor for crop				
	Corn	Small grain	Tobacco	Soybeans	Row crops
5. Late July-early August					
Anne Arundel	0.45	0.07	0.14	-	0.22
Calvert	0.45	0.07	0.14	-	0.21
Charles	0.48	0.07	0.14	-	0.27
Howard	0.41	0.07	-	0.42	-
Montgomery	0.36	0.07	-	0.42	-
Prince Georges	0.37	0.07	0.20	-	0.29
St. Marys	0.51	0.07	0.10	-	0.29
6. Early August-mid-September					
Anne Arundel	0.26	0.07	0.32	-	0.31
Calvert	0.26	0.07	0.32	-	0.31
Charles	0.28	0.07	0.32	-	0.30
Howard	0.24	0.07	-	0.28	-
Montgomery	0.21	0.07	-	0.28	-
Prince Georges	0.27	0.07	0.42	-	0.34
St. Marys	0.29	0.07	0.39	-	0.32

Prince Georges County: 1,800 acres of corn were shifted to pasture; 6,700 acres of row crops were shifted to pasture; and 1,450 acres of small grains were shifted to pasture.

St. Marys County: 830 acres of corn were shifted to pasture; 180 acres of row crops were shifted to pasture; and 3,200 acres of small grains were shifted to pasture.

2.3.3.1.7 Nutrients

Concentrations of nutrients in the Patuxent Basin soils were sought from regional soil scientists and from soil test results. Information relating to total nutrient content was not readily obtainable; most information reflected available nutrient concentrations. The concentrations of available phosphorus are shown in Table 2-39. Total phosphorus was estimated from general soils information for the region. For purposes of nonpoint load estimates, a value of 200 ppm phosphorus was used for the coastal region (Anne Arundel, Calvert, Charles, and Prince Georges counties); and 500 ppm for the Piedmont region (Howard and Montgomery counties).

TABLE 2-39. SOIL NUTRIENT CONCENTRATIONS IN THE PATUXENT RIVER BASIN

County	Available phosphorus[a]	Total nitrogen[b]
Anne Arundel	28	1,580
Calvert	29	1,480
Charles	24	1,540
Howard	20	1,800
Montgomery	20	1,660
Prince Georges	24	1,630
St. Marys	26	1,480

[a] Total phosphorus is estimated to be 200 ppm in the coastal region and 500 ppm in the Piedmont.

[b] Available nitrogen is assumed to be 10% of total.

Table 2-39 also shows the total concentration of nitrogen in soils. These values were obtained from the Jenny equation.

Enrichment ratios for nitrogen were determined using the method described in section 2.1.3.1.7. The average value for the seven counties in the Patuxent River Basin is 1.62 ± 0.08. An enrichment ratio of 1.6 was used.

The input of rainfall nitrogen was also estimated using procedures outlined in section 2.1.3.1.7. The value estimated for the Patuxent River Basin is 0.0059 lb/acre/event.

2.3.3.1.8 Sediment Delivery Ratio

Based on available information, sediment delivery ratios for the Patuxent Basin cannot be quantified. A value of 0.1 was arbitrarily chosen for estimating nonpoint loads.

2.3.3.2 Load Determination

The estimated nonpoint loads for the basin are shown in Table 2-40.

TABLE 2-40. ESTIMATED STREAM LOADING RATES FOR THE AVERAGE PATUXENT EVENT, SEDIMENT DELIVERY RATIO = 0.1

	ton/mile/event	lb/mile/event				
		Phosphorus			Nitrogen	
Subbasin	Sediment	Total	Available	BOD_5	Total	Available
1	98	65	8.5	940	480	57
2	104	58	7.5	1,050	540	65
3	67	37	4.8	700	360	42
4	114	70	8.6	1,180	600	72
5	60	75	4.4	660	340	39
6	101	163	6.5	1,160	590	68
7	97	153	6.1	1,050	530	58
8	67	108	4.3	750	380	44

2.3.4 Urban Nonpoint Sources

Two significant urban centers are located in the Patuxent River Basin: Bowie (population 41,000) and Laurel (population 14,500). Neither community has combined sewers, so there are no combined sewer overflows in the basin.

Public Works officials in Bowie and Laurel were contacted to obtain lengths of streets in the two municipalities. These values were used in conjunction with deposition rates of solids, BOD_5, available nitrogen, total nitrogen, available phosphorus, and total phosphorus. Estimated annual loads for these pollutants in urban runoff are shown in Table 2-41.

TABLE 2-41. ESTIMATED ANNUAL LOADS FOR URBAN RUNOFF: PATUXENT RIVER BASIN

Towns:
Bowie; population = 41,000; curb-miles = 260
Laurel; population = 14,500; curb-miles = 70

Constituent	Loading Rate (lb/curb mile/day)	Loads (ton/yr) Bowie	Loads (ton/yr) Laurel
Solids	5.90	28,000	7,500
BOD_5	3.6	170	46
Available nitrogen	0.25	12	3
Total nitrogen	0.60	29	8
Available phosphorus	0.06	3	1
Total phosphorus	0.12	6	2

2.3.5 Nonpoint Source Impacts on Water Quality

Instream concentration estimates for nitrogen and phosphorus for the Patuxent River, based on the loads estimated above, are presented in Section 3.4.4.2.2 of Volume II. No water quality data were available for comparison.

2.4 DEMONSTRATION EXAMPLE: WARE RIVER BASIN

2.4.1 Character of the Basin

The Ware River is the smallest of the four river basins evaluated in the Chesapeake Bay phase of the study. Its area is only about 62 sq miles. The basin is located entirely within Gloucester County, Virginia, off Mojack Bay, adjacent to Chesapeake Bay. The land consists mainly of forest and swamps with small areas of agricultural development. There are no urban areas in the basin. The largest town in the basin is Gloucester, with a population of 700.

For analysis the basin has been divided into four subbasins. Table 2-42 gives the areas of the subbasins and the lengths of the principal streams. Figure 2-4 shows the basin and subbasins.

TABLE 2-42. WARE RIVER SUBBASINS

Subbasin	Area (acres)	Length of principal streams (miles)
Cow Creek	3,164	5
Beaver Dam Swamp	16,214	22
Fox Mill Run	10,678	14
Ware and Wilson Creek	9,491	16
Total	37,547	

The average annual rainfall for the Ware Basin is about 45 in., and the wettest months are July and August. Dry months are October through December.

2.4.2 Nonpoint Load Estimation Methodology--An Overview

The same nonpoint source assessment procedure which was applied to the Sandusky River Basin was used for the Ware. The Ware River Basin contains no significant urban sources of nonpoint pollution.

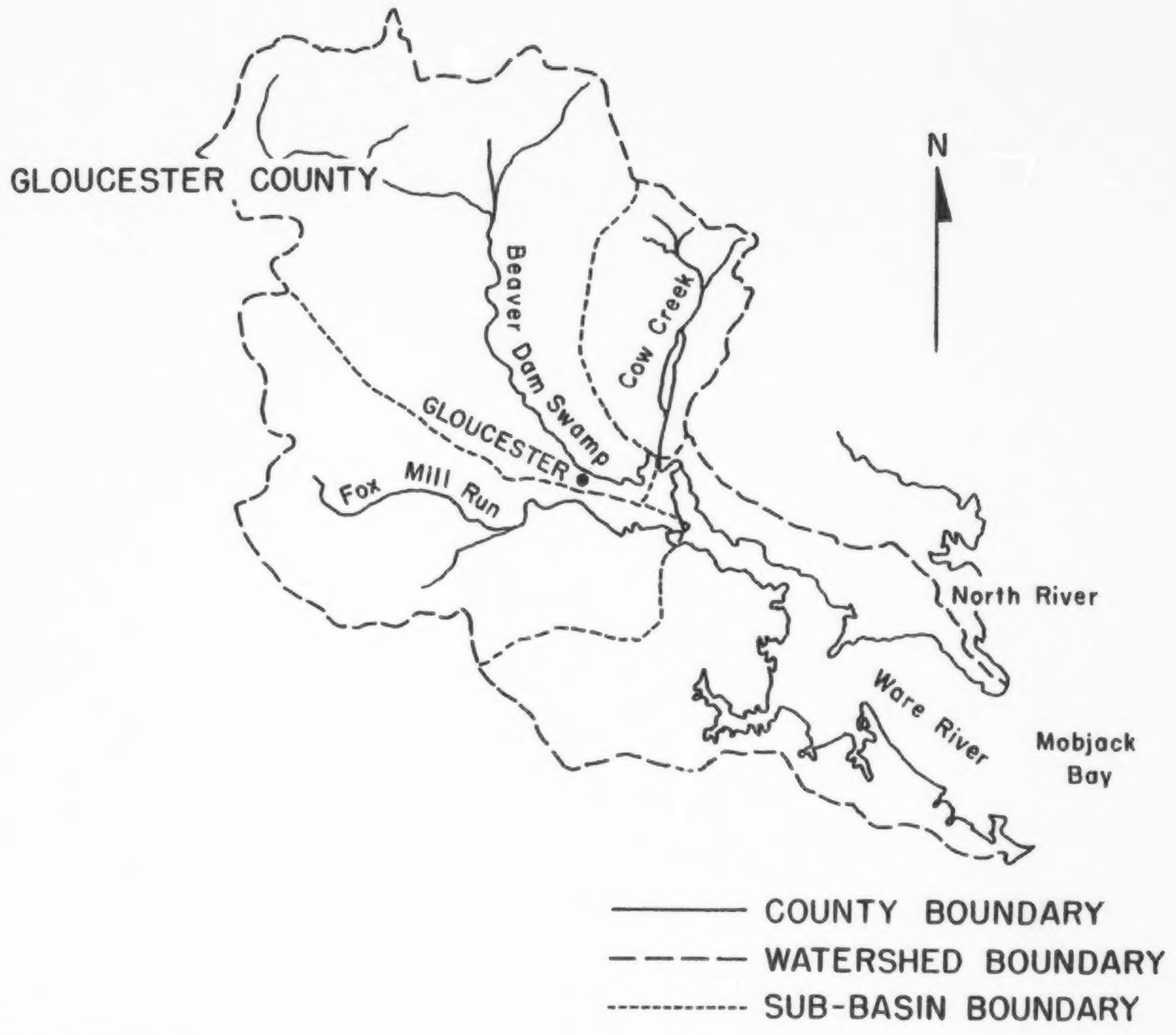
GLOUCESTER COUNTY
N
Beaver Dam Swamp
Cow Creek
GLOUCESTER
Fox Mill Run
North River
Ware River
Mobjack Bay
COUNTY BOUNDARY
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY

Figure 2-4. Ware River Basin and Subbasins.

2.4.3 Rural Nonpoint Sources

2.4.3.1 Parameter Evaluation

2.4.3.1.1 Rainfall Factor (R)

There are no recording rain gauges in the Ware River Basin. The nearest station with recoverable data is at Williamsburg, Virginia, about 12 miles southwest of the basin. Table 2-43 shows the periods analyzed (based on compatibility with the study presented in Volume II) and the EI_{30} values calculated for Williamsburg. The data were obtained from the National Climatic Center.

TABLE 2-43. EVALUATION OF EI_{30} FOR THE WARE RIVER BASIN

	Total rainfall at Williamsburg (in.)	EI_{30} for Williamsburg
May 7, 1967	1.15	7.1
August 23-25, 1967	3.2	28.7
May 27-June 2, 1968	No data	
August 3-September 1969	No data	
April 23-24, 1970	No data	
April 23-29, 1972	No data	
May 19-25, 1972	Data problems	
June 21-23, 1972	2.4	13.9
April 8-14, 1973	No data	
April 26-May 2, 1973	No data	
June 23-29, 1974	No data	
July 24-27, 1974	3.3	30.7
June 17, 1974	0.8	4.2
September 4-10, 1974	No data	
July 12-18, 1975	Data problems	
September 1-7, 1975	No data	
September 23-29, 1975	No data	
April 1-7, 1976	No data	
May 1-7, 1976	Data problems, late April	
September 16-22, 1976	No data	
April 4-5, 1977	1.6	6.4
April 24, 1977	0.9	2.9
April 24-25, 1972	0.9	2.8
August 17-18, 1972	1.4	13.0
August 24, 1977	2.7	42.8
Total		152.5

As can be seen from the entries in Table 2-43, the rainfall data for Williamsburg are plagued with problems. As a result, there is a considerably more uncertainty in the definition of a rainfall event for the Ware Basin than for the other basins studied. Better data may have been available for Norfolk, Virginia. However, Norfolk is about 50 miles from the Ware Basin. Therefore, we chose to use data from Williamsburg, which is closer.

For the 10 storm periods with data, the average value of EI_{30} is 15.3; without the largest event, the average is 12.2. The events are distributed over the period April through September, and the most erosive rainfall occurs in late summer.

2.4.3.1.2 Soil Erodibility Factor (K)

The weighted K factor for the soils in the Ware River Basin is 0.25. This value was established by estimating areas of particular soil series within soil associations and using the acreage as the weighting factor to determine average K values for the associations. Soil erodibility was fairly uniform throughout the basin; hence, the single K value for all the soils.

2.4.3.1.3 Slope Factors (L and S)

The slopes and slope lengths for LRA 149 as developed by the Soil Conservation Service were used to estimate LS values. LRA 149 (Northern Coastal Plain) includes Gloucester County and the Ware River Basin. Values for slopes and slope lengths are tabulated in Appendix I.

2.4.3.1.4 Cover Factor (C)

The cover factors (C) were developed for specific crops based upon cropping patterns and rotations. The base year for the nonpoint analysis is 1977. The areas of principal crops (corn, soybeans, wheat and barley) in Gloucester County for 1977 were presented in Table 2-44, along with areas of the crop rotations. Crop acreage was assumed to be uniformly distributed throughout the county and approximately 28 percent of the county is in the Ware Basin.

TABLE 2-44. AGRICULTURAL DATA FOR GLOUCESTER COUNTY (WARE RIVER BASIN), VIRGINIA FOR 1977

Crops	(acres)
Corn	7,300
Soybeans	6,500
Wheat	1,400
Barley	1,100
Total	16,300
Rotations	
Continuous corn	800
Corn-soybeans (2-yr rotation)	8,000
Corn-small grains-soybeans (2-yr rotation)	7,500

The crop rotations were used to establish C factors for various stages of growth for corn, soybeans, and small grains (wheat and barley). Cover factors are tabulated in Table 2-45.

TABLE 2-45. COVER FACTORS (C) BY RAINFALL INTERVAL FOR THE WARE RIVER BASIN

Group of events	Corn	Soybeans	Small grain
Early April to mid-April	0.46	0.08	0.02
Mid-April to mid-May	0.77	0.15	0.02
Mid-May to mid-June	0.64	0.38	0.02
Mid-June to mid-July	0.50	0.38	0.05
Mid-July to mid-August	0.24	0.30	0.05
Mid-August to mid-September	0.24	0.13	0.05

2.4.3.1.5 Support Practice Factor (P)

The practice factors (P) based on information for Gloucester County as reported in the 1967 CNI were used for the Ware River Basin. More current information was not available. The P values used are given in Appendix I.

2.4.3.1.6 Land Use Within The Ware River Basin

The changes in land use based on comparison of the 1967 CNI and the 1977 agricultural statistics data for Gloucester County are the following: 1,000 acres of row crops (soybeans) shifted to corn; 1,800 acres of row crops shifted to pasture; and 300 acres of small grain shifted to pasture.

2.4.3.1.7 Nutrients

Total soil phosphorus concentration in soils in the Ware River Basin is estimated to be about 200 ppm. Of this total, 38 ppm is present as available phosphorus.

Total soil nitrogen as estimated by the Jenny equation is 1,410 ppm.

Total nitrogen in rainfall is estimated to be 0.0027 lb/acre/event.

2.4.3.1.8 Sediment Delivery Ratio

No data are available for estimating a sediment delivery ratio. A value of 0.1 was used in the analysis.

2.4.3.2 Load Determination

Estimates of nonpoint loads are given in Table 2-46.

TABLE 2-46. ESTIMATED STREAM LOADING RATES FOR THE AVERAGE WARE EVENT; SEDIMENT DELIVERY RATIO = 0.1

	tons/mile/event	lb/mile/event				
		Phosphorus			Nitrogen	
Subbasin	Sediment	Total	Available	BOD_5	Total	Available
Cow Creek	5.1	4.7	0.9	71	37	6
Beaver Dam Swamp	5.9	5.8	1.1	83	43	6
Fox Mill Run	6.1	5.8	1.1	85	45	6
Ware and Wilson Creek	4.7	4.7	0.9	66	35	5

2.4.4 Nonpoint Source Impacts on Water Quality

Instream concentration estimates for sediment, nitrogen, phosphorus, and BOD_5 are presented in Section 3.5.5 of Volume II. These concentration estimates are based on the loads for rural nonpoint sources presented above.

2.5 DEMONSTRATION EXAMPLE: OCCOQUAN RIVER BASIN

2.5.1 Character of the Basin

The Occoquan River is located in Northern Virginia. The drainage area is approximately 480 sq miles; the river discharges into the Potomac River below the Washington, D.C. metropolitan area. The basin is located entirely within LRA 148--Northern Piedmont.

The principal land uses of the Occoquan River Basin are agriculture and forestry. There are significant areas of urban development at Manassas and Manassas Park. A major urban area--Fairfax, Virginia--is located on the northern periphery of the basin. Much of the area around these communities is low density surburban housing.

The Occoquan River is dammed near its confluence with the Potomac. The reservoir behind the dam is used as a major public water supply for the Washington, D.C.-Northern Virginia area.

The average annual rainfall for the area is about 41 in. (Washington, D.C.) and is fairly evenly distributed throughout the year. The wettest months are July and August, and driest months occur in winter.

For purposes of evaluation, the Occoquan River Basin has been divided into five subbasins. Figure 2-5 is a map delineating the Occoquan Basin and subbasins. Areas of the subbasins and lengths of principal streams are given in Table 2-47.

TABLE 2-47. OCCOQUAN RIVER SUBBASINS

	Area (acres)	Length of principal streams (miles)
Kettle Run	15,104	16
Cedar Run	115,463	37
Broad Run	42,178	22
Bull Run	82,190	43
Occoquan	52,022	38
Total	306,957	

2.5.2 Nonpoint Source Load Estimation Methodology--An Overview

As for the other basis the procedure used for load estimation in the Occoquan was the same as described for the Sandusky. Details may be found in Section 2.1. Both urban and rural nonpoint sources exist in the Occoquan Basin.

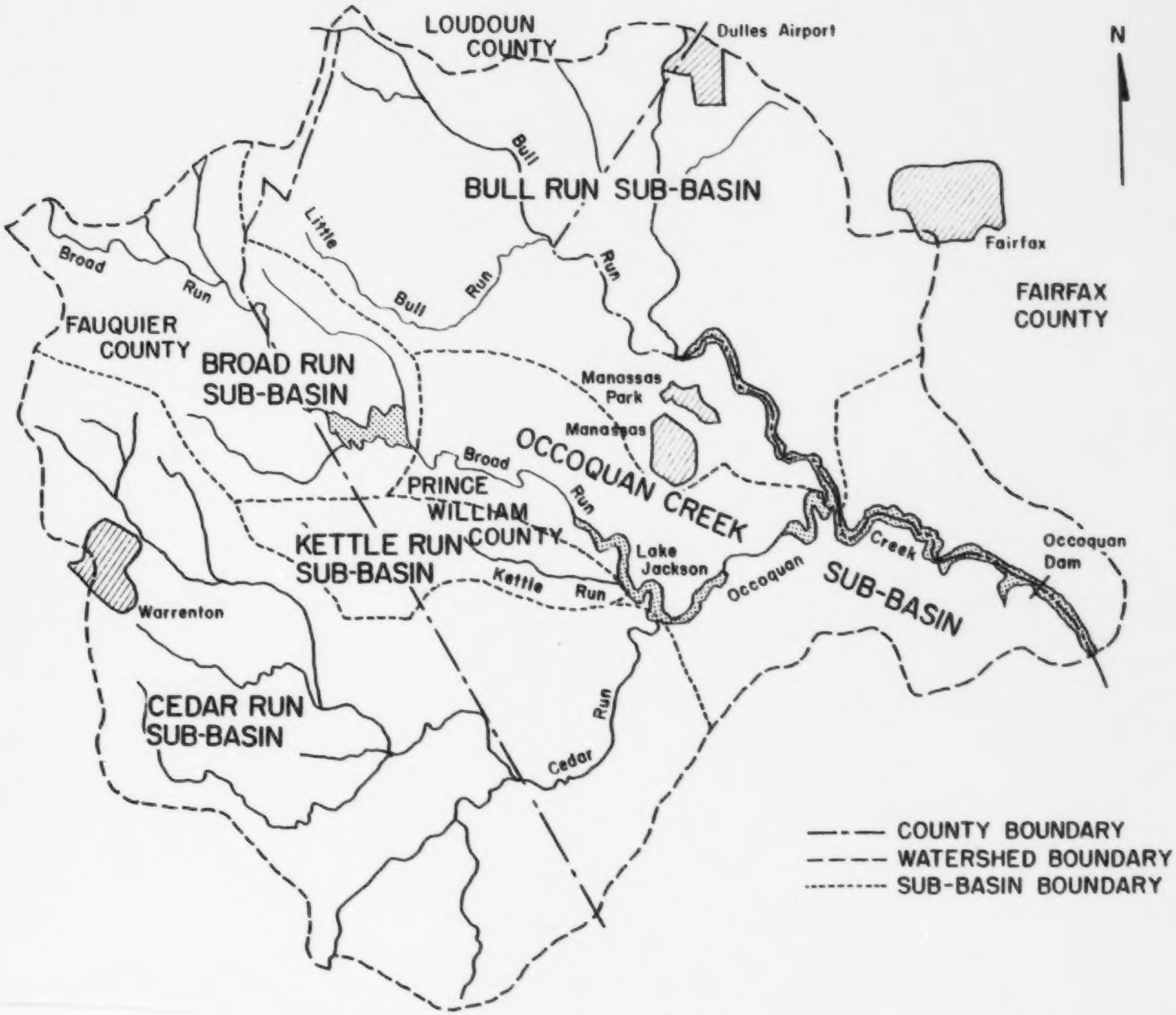
LOUDOUN COUNTY
Dulles Airport
N
Bull
BULL RUN SUB-BASIN
Fairfax
Little
Bull
Run
Run
Broad
Run
FAIRFAX COUNTY
FAUQUIER COUNTY
BROAD RUN SUB-BASIN
Manassas Park
Manassas
Broad
Run
OCCOQUAN CREEK
PRINCE WILLIAM COUNTY
KETTLE RUN SUB-BASIN
Kettle
Run
Lake Jackson
Occoquan
Creek
SUB-BASIN
Occoquan Dam
Warrenton
CEDAR RUN SUB-BASIN
Run
Cedar
COUNTY BOUNDARY
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY

Figure 2-5. Occoquan River Basin and Subbasins.

2.5.3 Rural Nonpoint Sources

2.5.3.1 Parameter Evaluation

2.5.3.1.1 Rainfall Factor (R)

The recording station at The Plains, Virginia, was chosen for use in determining EI_{30} values for the Occoquan River Basin. There are several stations around the basin, but none was found to be very satisfactory in terms of data availability, e.g., length of record, completeness of records, etc. Thus, the station at The Plains represents the best choice of a bad lot.

Table 2-48 shows the periods for which rainfall data were analyzed for Plains. Data were obtained from the National Climatic Center in Asheville, North Carolina. Events were selected based on their compatibility with the analysis presented in Volume II.

TABLE 2-48. EVALUATION OF EI_{30} FOR THE OCCOQUAN BASIN

	Rainfall at The Plains (in.)	EI_{30}
May 13-16, 1971	2.4	11.0
April 21-24, 1971	1.8	10.3
May 20-26, 1972	Data problems	
June 21-27, 1973	Hurricane Agnes - neglected	
April 25-27, 1973	2.3	7.0
May 27-28, 1973	1.3	6.2
May 11-12, 1974	1.8	21.9
June 2-8, 1974	No data	
August 31-September 6, 1975	No data	
March 31-April 1, 1976	1.6	13.6
September 15-16, 1976	2.3	12.0
Total	13.7	82.0

Note: Average of seven events = 11.7;
Average without largest = 10.0

For the seven events for which data were available during the period 1971 to 1976, the average EI_{30} is 11.7. Average annual EI_{30} value for the basin is about 200. The events are scattered throughout the growing season. However, data gaps are frequent in the summer months. These gaps led to the definition of a rainfall interval encompassing the period mid-June to early October, which also encompasses a major segment of the crop growing season. Thus, when the rainfall intervals are integrated with crop growing data to ascertain appropriate factors for the Occoquan Basin, there is difficulty in providing accurate C factors for all periods.

2.5.3.1.2 Soil Erodibility Factor (K)

Soil surveys were available for only three of the four counties in the Occoquan Basin. It was determined that the survey for Fauquier County could be used to provide a representative K value for the entire Occoquan Basin.

Analysis of the county soil survey maps showed that K values for the predominant series varied from 0.28 to 0.43. However, when the K values were weighted according to areal extent of specific soil series, it was found that both the predominant and average K value for the Fauquier County was 0.32. A K value of 0.32 was used for estimating soil loss from the entire Occoquan River Basin.

2.5.3.1.3 Slope Factors (L and S)

Slopes and slope lengths for LRA 148 were obtained from the nonpoint calculator data base. These values are tabulated in Appendix I. More appropriate data were not readily available.

2.5.3.1.4 Cover Factor (C)

The base year chosen for the analysis of the Occoquan River Basin is 1973. The areas of crops grown in the Occoquan Basin in 1973 are presented in Table 2-49. A large part of the corn grown in the region is used for silage.

TABLE 2-49. AGRICULTURAL DATA FOR COUNTIES IN THE OCCOQUAN RIVER BASIN IN 1973

County	Crop area (10^3 acres)					
	Corn for grain	Corn for silage	Soybean	Wheat	Barley	Total
Fairfax	Virtually no cropping; all nonurban land assumed to be pasture					
Fauquier	14.1	14.1	1.1	3.0	2.2	34.5
Loudoun	22.0	4.0	0.8	5.3	3.0	35.1
Prince William	3.3	1.7	-	0.9	0.4	6.3

Six crop rotation patterns were identified through contact with county agents. These are:

1. Continuous corn (annual rotation).
2. Corn-small grain (wheat and barley) (2-yr rotation).
3. Soybean-small grain (2-yr rotation).
4. Corn-corn-small grain (3-yr rotation).
5. Corn-corn-soybean (3-yr rotation).
6. Corn-small grain-cover (rye)-cover (4-year rotation).

These rotation patterns were used in conjunction with the 1973 data to generate estimates of acres of crops in the rotations. These estimates are presented in Table 2-50.

The crop rotation data were used to generate C factors for each rotation as a function of stage of growth. These factors were then integrated with the rainfall event intervals and are tabulated in Table 2-51.

As discussed earlier, the rainfall data for the Occoquan River Basin are not good. The interval from mid-June to early October is much too long to calculate accurate C factors. During this period rapid crop growth occurs which directly affects C values.

TABLE 2-50. ESTIMATED AREAS OF PRINCIPAL CROP ROTATIONS BY COUNTY IN THE OCCOQUAN RIVER BASIN FOR 1973

County	Areas in rotation (10^3 acres) CC	CCSg	SbSg	CSg	CCSb	CSgCoCo
Fauquier	20.0	12.3	2.2	-	-	-
Loudoun	16.1	-	-	16.6	2.4	-
Prince William	3.7	-	-	0.9	-	1.7

CC = Continuous corn (annual rotation).
CCSg = Corn-corn-small grain (3-yr rotation).
SbSg = Soybean-small grain (2-yr rotation).
CSg = Corn-small grain (2-yr rotation).
CCSb = Corn-corn-soybean (3-yr rotation).
CSgCoCo = Corn-small grain-cover-cover (4-yr rotation).

TABLE 2-51. COVER FACTORS (C) BY RAINFALL INTERVAL AND BY CROP FOR THE OCCOQUAN RIVER BASIN

Group of Events	Crop Corn	Soybeans (Loudoun)	Soybeans (Fauquier)	Small grain
Early April to mid-April	0.12	0.25	0.19	0.14
Mid-April to late April	0.17	0.25	0.19	0.14
Late April to late May	0.17	0.25	0.09	0.08
Late May to mid-June	0.16	0.19	0.03	0.05
Mid-June to early October	0.13	0.16	0.26	0.20

2.5.3.1.5 Support Practice Factors (P)

The 1967 CNI contains the latest data concerning implementation of conservation practices on cropland. Lacking more current information, conservation practice factors for 1967 were assumed to be the same in 1973 for purposes of estimating soil loss. P values are tabulated in Appendix I.

2.5.3.1.6 Land Use Within The Occoquan River Basin

The changes in cropping patterns as reflected in the differences between the 1967 CNI and the 1973 base year were accommodated by shifting acreages within the various counties. The following land use shifts were made:

Fairfax County: 1,800 acres of corn were shifted to pasture; 430 acres of row crops were shifted to pasture; and 730 acres of small grain were shifted to pasture. (Note: Although there were agriculture products reported for Fairfax County in 1973, the portion of the county in the Occoquan Basin produced none of these.)

Fauquier County: 6,200 acres of small grain were shifted to corn; 5,000 acres of pasture were shifted to corn; and 1,100 acres of pasture were shifted to other row crops.

Loudon County: 800 acres of corn were shifted to row crops; 5,400 acres of corn were shifted to pasture; and 6,100 acres of small grain were shifted to pasture.

Prince William County: 210 acres of row crops were shifted to small grain; 890 acres of pasture were shifted to small grain; and 2,470 acres of pasture were shifted to corn.

2.5.3.1.7 Nutrients

The available soil phosphorus as reported in soil test information and the total soil nitrogen as calculated from the Jenny equation are presented in Table 2-52. The total phosphorus concentration in soil is estimated to be 480 ppm from information in the nonpoint calculator data base.

The nutrient enrichment ratio was found to be 2.14 ± 0.08. The enrichment ratio used for estimating nonpoint loads was 2.1.

Nitrogen in rainfall was estimated to be 0.0052 lb/acre/event.

TABLE 2-52. SOIL NUTRIENT CONCENTRATIONS IN THE OCCOQUAN RIVER BASIN

County	Average nutrient concentration in soil (ppm)	
	Available phosphorus[a]	Total nitrogen[b]
Fairfax	34	1,640
Fauquier	20	1,750
Loudoun	22	1,640
Prince William	27	1,520

[a] Total phosphorus is approximately 420 ppm.
[b] Available nitrogen is assumed to be 10% of total.

2.5.3.1.8 Sediment Delivery Ratio

Two sediment delivery ratios were arbitrarily used in the evaluation of the Occoquan River Basin--0.1 and 0.2. This basin has greater physiographic relief than the other Chesapeake basins, and the sediment delivery ratio may be larger than those of the other basins. Sediment delivery ratios of both 0.1 and 0.2 were used in the Occoquan evaluation in Volume II. Details of the analysis are presented there. The information needed for determining delivery ratios for the basin was not available.

2.5.3.2 Load Determination

The nonpoint loads estimated for the Occoquan River Basin are presented in Table 2-53. The two sets of entries reflect the use of the two delivery ratios (0.1 and 0.2) used in the analysis.

2.5.4 Urban Nonpoint Sources

Urban nonpoint annual lands for the principal municipalities in the Occoquan River Basin are presented in Table 2-54. These loads were estimated by multiplying street curb-miles for the cities (Manassas and Manassas Park) by deposition rates as reported by Sartor and Boyd (1972).

TABLE 2-53. ESTIMATED STREAM LOADING RATES FOR THE AVERAGE OCCOQUAN EVENT (lb/mile/event)

Subbasin	Sediment[a]	Phosphorus		BOD_5	Nitrogen	
		Total	Available		Total	Available
Sediment delivery ratio = 0.1						
Kettle Run	21	42	2.4	290	150	20
Cedar Run	77	160	7.0	1,130	580	73
Broad Run	46	90	4.4	680	350	44
Bull Run	36	81	5.0	500	260	35
Occoquan	25	54	3.8	330	170	24
Sediment delivery ratio = 0.2						
Kettle Run	41	84	4.7	580	290	34
Cedar Run	153	320	13.9	2,270	1,150	130
Broad Run	92	180	8.8	1,350	690	78
Bull Run	73	160	10.0	990	510	60
Occoquan	50	110	7.6	660	340	40

[a] Sediment units are ton/mile/event.

TABLE 2-54. ESTIMATED ANNUAL LOADS FROM URBAN RUNOFF: OCCOQUAN RIVER BASIN

Towns: Manassas Park - Population = 8,500; curb-miles = 28
Manassas - Population = 14,000; curb-miles = 102

Constituent	Rate (lb/curb-mile/day)	Loads (tons/yr)	
		Manassas Park	Manassas
Solids	590	3,000	11,000
BOD_5	3.6	18	67
Total nitrogen	0.25	1.3	11.2
Available phosphorus	0.06	0.3	1.1
Total phosphorus	0.12	0.6	2.3

2.5.5 Nonpoint Source Impacts On Water Quality

The water quality impacts associated with the nonpoint source loads estimated in the preceding sections are considered in Sections 3.6.2 to 3.6.4 of Volume I.

CHAPTER 3

DETERMINATION OF NUTRIENT FLUXES IN STREAMS, WITH CASE STUDIES OF THE POTOMAC AND SUSQUEHANNA RIVERS

3.1 INTRODUCTION

Determination of long-term average quantities of nutrients discharged by a stream is not an easy task. However, it is important because of the potential impact of these nutrients on estuaries or lakes into which the stream might flow. A number of approaches could be used to determine nutrient fluxes, the most reliable being the monitoring of the stream's nutrient concentration levels over a long period of time. Resource managers often need estimates of important environmental quantities but are not able to afford the long delay associated with extensive experimental work. This report describes an approach, along with two applications, for obtaining estimates of fluxes of sediment-associated nutrients in river basins. The approach is intended to provide useful results with only a minimum amount of new information. It is not designed to give definitive answers but rather to provide assistance in obtaining upper and lower limits on the average nutrient flux of a stream.

The procedure used to estimate nutrient flux is described in section 3.2. Section 3.3 reports the results of its application to the Potomac and Susquehanna River Basins.

3.2 METHODOLOGY

This section presents a procedure for estimating fluxes of sediment-associated nutrients in river basins. To make such estimates using the approach outlined, gross soil loss must be determined for a number of subbasins

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in the watershed, and measured values of sediment yield for the basin must be available. The procedure for determining nutrient fluxes is the following:

1. Divide the watershed into subbasins.

2. Determine the soil loss in each subbasin using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

3. Determine the sediment discharge for the basin based on measurements; a long-term average is preferred (near 20 years).

4. Estimate gross nutrient loads for each subbasin based on gross soil loss and the soil concentration of the nutrient.

5. Assuming that the nutrient moves in association with sediment, with a possible enrichment, limits on the nutrient flux from the watershed may be estimated based on the constraint that the sediment discharge for the basin equals the average measured discharge.

The soil loss for each subbasin is found using the USLE. The average sediment discharge Y_s for the entire basin can then be estimated by:

$$Y_s = \Sigma\gamma_i Y_i$$

where Y_i = soil loss for subbasin i
γ_i = sediment delivery ratio for subbasin i

The sediment delivery ratios are generally unknown. An average value for the entire basin is given by:

$$\bar{\gamma} = \frac{Y_{sm}}{\Sigma Y_i}$$

where Y_{sm} = measured, average sediment discharge for the basin (sediment originating from sheet and rill erosion)*

The nutrient is assumed to be associated with the sediment; nutrient discharge Y_x is given by:

$$Y_x = \Sigma\gamma_i r_i [x_i] Y_i$$

where $[x_i]$ = the soil concentration of nutrient x in subbasin i
r_i = the enrichment ratio for x_i

The enrichment ratio is the ratio between the nutrient concentration in the eroded sediment and that in the undisturbed soil. It accounts for the fact that nutrients are associated more (on a per unit volume basis) with the smaller soil particles than with the larger ones and that there is a preferential erosion and transport of the smaller particles.

Using an expression such as that given above for Y_x, it is possible to determine the nutrient flux from the watershed. To do so it is first necessary to evaluate the parameters in the equation. The sediment delivery ratios, γ_i, are particularly difficult to estimate. What is proposed here is a procedure that allows upper and lower limits on the nutrient flux, Y_x, to be determined based on a knowledge of the other factors in the above equation for Y_x. In addition, an average nutrient flux can be estimated using the basinwide average value for γ and $\bar{\gamma}$.

The physical argument for assigning upper and lower limits to the nutrient flux is essentially the following. Some portions of a watershed may yield larger quantities of nutrient per unit of sediment discharge than other portions. The larger than average values are due to higher soil concentrations of the nutrient and possibly to a higher degree of enrichment than exists elsewhere. The upper limit on the nutrient discharge would be established by assuming that all sediment comes from those parts of the watershed yielding the highest relative amounts of nutrient per unit of sediment. These regions would be assumed to supply the sediment needed to provide the sediment discharge observed for the basin. In essence, such regions would be assumed to have high delivery ratios; delivery ratios elsewhere would be zero. This arrangement would provide the maximum possible nutrient flux from the basin since there would be no other region or combination of regions within the basin which could provide a higher flux, given that the sediment discharge for the total watershed is fixed.

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* Sediment discharge associated with sheet and rill erosion is equal to total sediment discharge minus sediment discharge originating from other sources such as streambank and gully erosion and roadbank erosion.

An additional requirement concerning the estimation of the maximum flux is that the product $\gamma_i r_i$ in the expression for Y_x would always be less than or equal to 1 for each subbasin. If $\gamma_i r_i$ exceeds 1, Y_x could be larger than the total nutrient contained in the soil. This limitation on $\gamma_i r_i$ means that in finding an upper limit for Y_x, delivery ratios cannot be increased without considering the enrichment that occurs.

A similar argument can be used to determine a lower limit on nutrient flux. To find a lower limit, those areas in the basin providing the least nutrient flux per unit of sediment discharge are assumed to provide the sediment discharge from the basin. These areas have the lowest values of soil concentration of the nutrient and enrichment ratios.

The above argument for setting upper and lower limits on nutrient flux may be expressed more succinctly mathematically. The upper limit on nutrient flux is found by maximizing the expression above for Y_x subject to a constraint on sediment discharge for the basin. Similarly, the lower limit on nutrient flux may be found by minimizing Y_x subject to the same constraint.

The upper (lower) limit on Y_x is found as follows:

$$\begin{array}{ll} \text{maximize} & \Sigma\gamma_i r_i[x_i]Y_i \\ \text{(minimize)} & \\ & \\ \text{subject to} & \Sigma\gamma_i Y_i = Y_{sm} \end{array}$$

where $0 \leqq \gamma_i \leqq 1/r_i$

The constraint requires that the sediment discharge for the basin be equal to the measured value; γ_i is less than or equal to $1/r_i$ since if it were not, $\gamma_i r_i$ could be greater than 1, which would mean that more nutrient is delivered than originally existed in the soil.

This procedure requires no assumptions concerning the sediment delivery ratios. It will determine those delivery ratios which maximize or minimize the nutrient flux. The critical assumptions are (a) that the nutrient is transported with the sediment, (b) that there is no net uptake or loss of nutrient in the stream, and (c) that enrichment ratios can be defined.

To clarify these assumptions, some discussion of sediment transport in a watershed is necessary. Sediment movement in a watershed may be considered to be composed of three stages: the initial dislodging of soil particles; upland transport and deposition of sediment before a stream channel is reached; and channel transport. It is assumed that there is no long-term accumulation of sediment in a stream channel. Long-term deposition of sediment is assumed to occur in the upland stage of sediment transport. The sediment delivery ratio accounts for he efficiency of such upland transport. Nutrients move with the eroded soil and are enriched. The enrichment ratio specifies the degree of enrichment that occurs between point of origin and stream channel. After the nutrient is in a stream channel, part or all of it may change into a soluble form. However, it is assumed that no net long-term losses or additions of the nutrient occur in the stream channel. If from a long-term perspective, sediment and nutrients can be treated as conservative constituents while being transported by streams, then the enrichment ratio (r) and the assumption concerning sediment-nutrient association need apply only before the nutrient reaches a stream channel.

Such assumptions mean that the analysis described is only appropriate for determination of very long-term average nutrient fluxes. It is possible to apply it to short time periods, but such an application will encounter difficulties. First, for a given short time period there may be losses of sediment or nutrient in the channel or additions from the channel. Second, the soil losses determined using the USLE are long-term estimates.

An average value of nutrient flux can be determined assuming that the average delivery ratio for the nutrient is the same as for sediment in the basin. Then,

$$\overline{Y}_x = \overline{\gamma}\ \Sigma r_i[x_i]Y_i$$

For the approach just outlined, the differences between the estimated average value and the estimated upper and lower limits on nutrient flux are determined by the degree of homogeneity of the product $r_i[x_i]$ throughout the basin. For a completely homogeneous basin, the average value and the upper and lower limits are the same.

Since the approach described assumes that the nutrient yield is correlated with sediment yield, it will not be a valuable method for dealing with nitrogen. However, it should be of value in estimating fluxes of total phosphorus. (The procedure will also be of value for use with any other constituents which are associated with sediment, not just nutrients.)

The method described has been applied to the Potomac and Susquehanna River Basins. Results are presented in the following section.

3.3 CASE STUDY: POTOMAC RIVER BASIN

The methodology outlined in the preceding section has been applied to the Potomac River to estimate the nonpoint-source-associated phosphorus flux from the basin at the Fall Line. The Fall Line separates the coastal plain from the Piedmont Plateau and crosses the Potomac at Great Falls near river mile 126. The river below the Fall Line is mostly tidal, and the head of tidewater is at Little Falls (river mile 117).

Figure 3-1 is a map of the Potomac River Basin showing the outline of the basin and the boundaries of eight subbasins into which the watershed has been divided. The entire basin has an area of 14,670 sq miles. Of this area, 11,430 sq miles are above Great Falls.

Long-term (October 1960 to present) suspended sediment records are available at Point of Rocks, Maryland, at river mile 159.5 (6 miles upstream from the Monocacy River) and at Jug Bridge on the Monocacy River (16.9 miles upstream from the mouth). The drainage areas above these points are 9,651 and 817 sq miles, respectively. The combined areas constitute 91.6% of the Potomac Basin above Great Falls.

The sediment that is delivered to the tidal portion of the river is apparently deposited there. Schubel and Carter (1976) indicate that the Potomac estuary is a net sink for sediment from the Chesapeake Bay. Therefore, the estimates made will be only for the nontidal portion of the basin.

Table 3-1 provides information on the eight subbasins shown in Figure 3-1. Using the USLE, estimates were made of gross soil loss in each subbasin along with gross loss of phosphorus, based on the soil concentration of the nutrient. Table 3-1 contains the areas for which land use information was available. The land use data are from the 1967 Conservation Need Inventory (CNI) and represent land use in the basin at that time. All calculations with the USLE used county portions of subbains which were then combined in each subbasin to give totals for the subbasins. Calculations were done with a procedure and data base described by Davis and Nebgen (1979); these are briefly discussed in Appendix I.

Comparing the areas in Table 3-1 with the basin areas given earlier indicates that 82% of the entire basin is inventoried, including 87% of the area above Great Falls. Inventoried land excludes federally owned land, urban areas, and small water areas.

Table 3-2 shows annual suspended sediment discharge data for the Potomac at Point of Rocks and the Monocacy at Jug Bridge. The 17-year average discharges at these two locations are 1.073×10^6 tons/year and 0.183×10^6 tons/year, respectively.

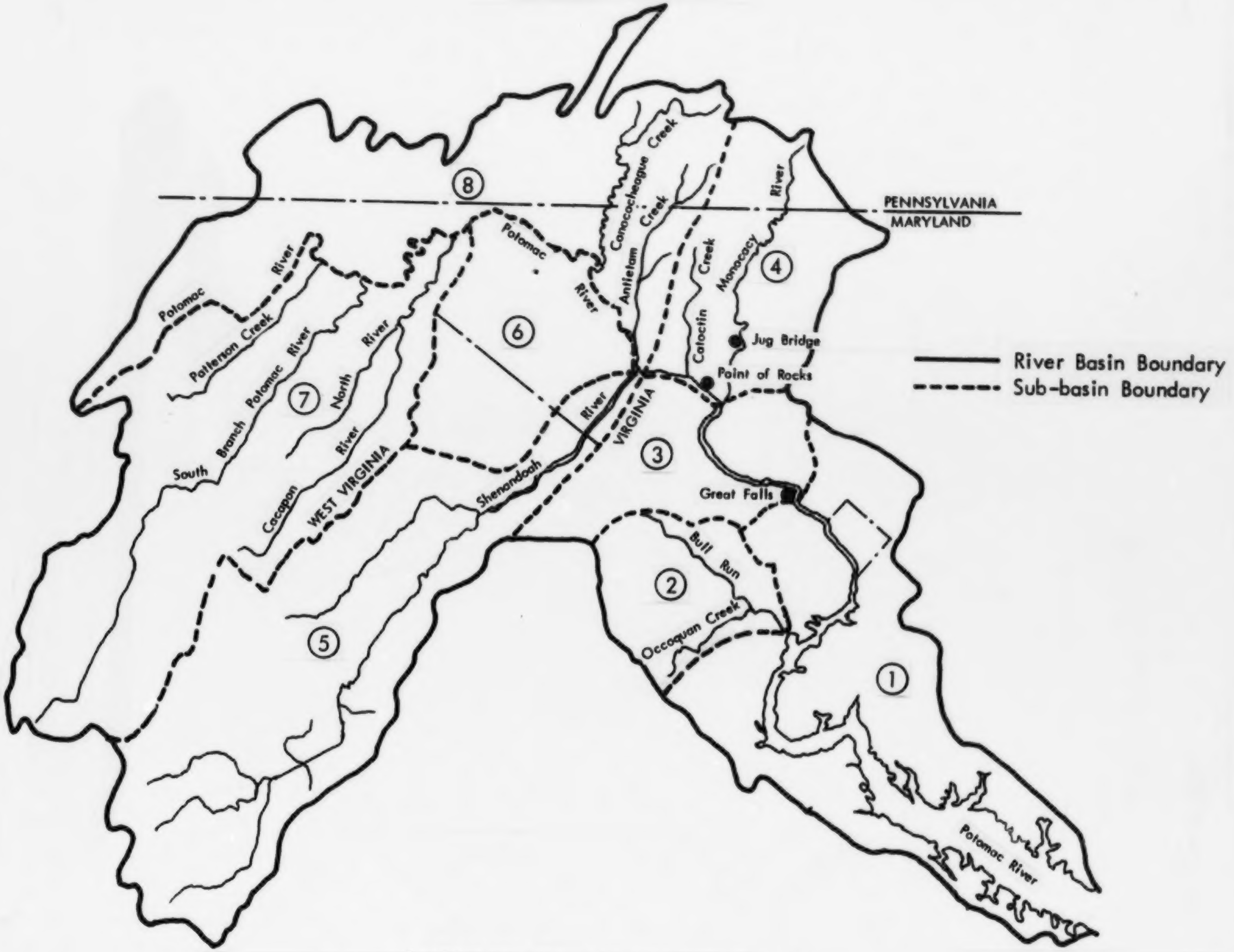
PENNSYLVANIA
MARYLAND
River Basin Boundary
Sub-basin Boundary
8
Conococheague Creek
Antietam Creek
Catoctin Creek
Monocacy River
4
Jug Bridge
Point of Rocks
Potomac River
6
River
Potomac
Patterson Creek
South Branch Potomac River
7
North River
Cacapon River
WEST VIRGINIA
VIRGINIA
Shenandoah River
3
Great Falls
Bull Run
2
Occoquan Creek
5
1
Potomac River

Figure 3-1. Potomac River Basin.

TABLE 3-1. POTOMAC RIVER BASIN SUBWATERSHEDS

(1) Subbasin	(2) Inventoried area (miles^2)	(3) Soil loss (tons/yr x 10^{-6})	(4) Subbasin avg. soil phosphorus conc. (ppm)	(5) Avg. soil phosphorus loss (lb/acre/yr)	(6) Phosphorus loss (tons/yr x 10^{-3})
1 Below Great Falls	1,620	4.7	260	2.4	1.2
2 Occoquan River	480	1.4	500	4.4	0.7
3 Above Washington	860	3.2	440	4.9	1.4
4 Monocacy River	1,050	5.6	430	7.2	2.4
5 Shenandoah River	2,120	12.0	300	5.3	3.6
6 Opequon Creek	880	3.7	300	3.9	1.1
7 South branch Potomac	2,560	5.9	300	2.2	1.8
8 North of river	2,460	10.5	300	4.0	3.2
Total	12,030	47.0			15.4

TABLE 3-2. SUSPENDED SEDIMENT DISCHARGES, POTOMAC RIVER [a]

Water year	Sediment discharge, Potomac River at Point of Rocks (tons)	Sediment discharge, Monocacy River at Jug Bridge (tons)
1961	1,104,726	123,299
1962	858,417	146,480
1963	1,107,089	113,026
1964	895,966	131,503
1965	652,176	106,851
1966	443,946	113,690
1967	1,129,158	155,032
1968	734,893	107,761
1969	156,865	72,507
1970	1,270,933	314,684
1971	1,375,032	185,449
1972	2,435,621	455,552
1973	1,533,788	240,378
1974	1,036,640	160,676
1975	1,595,278	311,531
1976	528,908	146,532
1977	1,377,571	222,654
Total	18,237,007	3,107,605

[a] Source: Water Resources Data for Maryland and Delaware, U.S. Geological Survey.

Assuming that the average annual sediment discharge per unit area from above both of these locations can be used to estimate sediment output for the 962-sq mile area located above Great Falls but not above the sediment gauging station, an annual average value at Great Falls of 1.372×10^6 tons/year is obtained.* Using the gross soil loss values from Table 3-1 for the area above Great Falls along with this sediment discharge gives an average sediment delivery ratio for the Potomac Basin above the Fall Line of 0.034, a value that is not unreasonable based on the size of the basin.

It should be noted that the 1967 land use information corresponds to a time period near the middle of the period of record for suspended sediment. Since land use changes during the 1961 to 1977 period are not considered, 1967 values are reasonable ones to use for average values.

Assuming that phosphorus moves in association with sediment (at least in the upland phase of transport), the approach can be applied to the Potomac to estimate limits for the annual flux of phosphorus at Great Falls.

The constraints on phosphorus flux are established by the estimated sediment discharge at Great Falls and the measured value for the Monocacy River. For the Monocacy River, the annual sediment discharge at Jug Bridge is 0.183×10^6 tons/year. This is for a drainage area of 817 sq miles. The gross soil loss for the entire Monocacy watershed (i.e., subbasin 4) (1,210 sq miles estimated for Table 3-1 assuming 87% inventoried) is 5.6×10^6 tons/year. Therefore, assuming that sediment yield is uniform throughout the watershed, the sediment delivery ratio, γ_4, for the Monocacy is:

$$\gamma_4 = \frac{(1{,}210/817)\ (0.183 \times 10^6)}{5.6 \times 10^6} = 0.048$$

---

* The contribution of bedload to the total sediment discharge has been neglected. At Point of Rocks the streambed is bedrock; the suspended load is less than about 10% sand and the suspended solids concentration is below 1,000 mg/L even during high flow periods. Neglect of any bedload contribution seems to be a very good assumption.

Also, the sediment discharge at Great Falls is 1.372×10^6 tons/year. The minimum phosphorus flux is then given by:

$$\text{minimize} \quad \sum_{i=3}^{8} \gamma_i r_i [P_i] Y_i$$

$$\text{subject to} \quad \sum_{i=3}^{8} \gamma_i Y_i = 1.372 \times 10^6$$

$$\text{and} \quad \gamma_4 = 0.048$$

where $0 \leqq \gamma_i \leqq 1/r_i$

Minimum soil phosphorus concentrations are in subbasins 5 to 8. In principle, subbasin 5 (the Shenandoah River) can satisfy the sediment constraint along with the Monocacy so that:

$$\gamma_4 Y_4 + \gamma_5 Y_5 = 1.372 \times 10^6$$

$$\gamma_5 = \frac{1.372 \times 10^6 - (1{,}210/817)\,(0.183 \times 10^6)}{12.0 \times 10^6}$$

$$= 0.092$$

$$\gamma_3 = \gamma_6 = \gamma_7 = \gamma_8 = 0$$

So, assuming that $r = 2$ for all subbasins,* the minimum P flux is:

$$Y_{P_{min}} = 2\gamma_4 [P_4] Y_4 + 2\gamma_5 [P_5] Y_5$$

$$= 890 \text{ tons/year}$$

The values of $[P_i]Y_i$ are taken from Column (6) of Table 3-1.

A maximum P flux (with $r = 2$ in all subbasins) can be found in the same manner:

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* The use of $r = 2$ is somewhat arbitrary. McElroy et al. (1976, p. 106) report values from 1.5 to 3.4. The value could be assigned more accurately by determining r_p on an event-by-event basis over many years and then averaging.

$$\text{maximize} \sum_{i=3}^{8} \gamma_i r_i [P_i] Y_i$$

$$\text{subject to} \sum_{i=3}^{8} \gamma_i Y_i = 1.372 \times 10^6$$

$$\text{and} \quad \gamma_4 = 0.048$$

where $0 \leqq \gamma_i \leqq 1/r_i$

Maximum soil phosphorus concentrations are in subbasins 3 and 4. Subbasin 4 is the Monocacy, for which an accounting has already been made. Subbasin 3 can supply sufficient sediment to satisfy the constraint at Great Falls.

$$\gamma_3 Y_3 + \gamma_4 Y_4 = 1.372 \times 10^6$$

$$\gamma_3 = \frac{1.372 \times 10^6 - (1{,}210/816)\ (0.183 \times 10^6)}{3.2 \times 10^6}$$

$$\gamma_3 = 0.34$$

$$\text{and} \quad \gamma_5 = \gamma_6 = \gamma_7 = \gamma_8 = 0$$

The maximum P flux is:

$$Y_{P_{max}} = 2\gamma_3 [P_3] Y_3 + 2\gamma_4 [P_4] Y_4$$

so $Y_{P_{max}} = 1{,}200$ tons/year

An average value of Y_p can be estimated by:

$$Y_p = \bar{\gamma} \sum_{i=3} r_i [P_i] Y_i \ ,$$

assuming that phosphorus is delivered in the same manner as sediment, with only an enrichment r. With r = 2 in each subbasin,

$$Y_p = (0.034)(2)(13{,}500)$$

$$= 920 \text{ tons/year}$$

The calculations concerning the P flux at Great Falls are summarized in Table 3-3.

TABLE 3-3. ESTIMATES OF AVERAGE ANNUAL PHOSPHORUS FLUX AT GREAT FALLS FROM NONPOINT SOURCES

	Tons/yr
Upper limit equal to gross phosphorus loss (subbasins 3 to 8)	13,500
Maximum flux with r = 2	1,200
Flux using basin average delivery ratio (0.034) and r = 2	920
Minimum flux with r = 2	890
Flux using basin average delivery ratio (0.034) and no enrichment	460

As Table 3-3 shows, the long-term average annual flux into the Potomac estuary from nonurban, nonpoint sources is in the range 890 to 1,200 tons/year (if r = 2). This assumes that phosphorus is associated with sediment, that the relationship between sediment and phosphorus is determined by the soil concentration of phosphorus, that a uniform enrichment of phosphorus by a factor of 2 occurs during transport, and that sediment contributions from other than sheet and rill erosion are negligible.

Measurement of long-term phosphorus fluxes on the Potomac are not available. However, an estimate of the nonpoint-source phosphorus flux at Great Falls for calendar year 1966 has been published (Jaworski, 1969). This estimate is for a very short period, and the estimate of the portion of the flux from nonpoint sources is based on a consideration of a single agricultural watershed (Catoctin Creek) and a single forested watershed (Patterson Creek) with an extrapolation from these measurements to the entire upper basin. Therefore, it would not be surprising if the 1966 results differed substantially from the estimate made here for a long-term average.

For the calendar year 1966, Jaworski reports 0.470×10^6 tons of sediment at Point of Rocks and 0.118×10^6 tons at Jug Bridge on the Monocacy. Using these numbers gives an estimate of suspended sediment discharge equal to 0.642×10^6 tons at Great Falls. The estimated total land-use-related phosphorus flux was 8,610 lb/day as PO_4, which is equivalent to 512 tons/year as phosphorus.

The estimates in Table 3-3 are for a long-term average sediment discharge at Great Falls of 1.372×10^6 tons/year. If the phosphorus yield in a given year (compared to the long-term average) varies in proportion to sediment yield, the estimated P flux for 1966 would be:

$$Y_{P_{1966}} = \frac{0.642 \times 10^6}{1.372 \times 10^6} (920) = 430$$

The maximum and minimum values (as in Table 3-3) would be 560 and 420 tons/year. These numbers agree rather well with the 512 tons/year value estimated by Jaworski. However, the agreement may be fortuitous. Proper verification of the estimates will require long-term monitoring of phosphorus yields from rural areas in the basin.

Sediment resulting from eroded streambanks and gullies contributes some portion of the sediment discharged by the Potomac. If this sediment has phosphorus concentrations less than those in the soil eroded from the land surface, the phosphorus flux in the stream will be less than that calculated in proportion to the fraction of sediment coming from streambanks and gullies. Assuming that the nutrient input from these sources can be neglected, phosphorus fluxes (as in Table 3-3) have been recomputed for various assumed contributions from gullies and streambanks. The results are shown in Table 3-4. Sediment from sources such as roadbanks and impervious areas have been neglected.

TABLE 3-4. SENSITIVITY OF ANNUAL PHOSPHORUS FLUX ESTIMATES TO STREAMBANK AND GULLY EROSION[a]

	Percentage of sediment discharge at Great Falls that originates in streambank and gully erosion (tons/yr)				
	0	5	10	15	20
Maximum flux with r = 2	1,200	1,140	1,080	1,020	960
Flux with basin average delivery ratio and r = 2	920	870	830	780	740
Minimum flux with r = 2	890	850	810	760	710

[a] Assumes no nutrient contributed by streambank and gully erosion.

The portion of the sediment originating in streambanks and gully erosion is probably within the range shown in Table 3-4; estimates of this type of erosion for the Potomac Basin have not been located. However, a study by the Soil Conservation Service (1977) estimates that the streambank contribution to total sediment discharge is 14% for a 220-sq-mile area in the Monocacy Basin. That report also uses values of 5 to 14% for other basins studied for the Baltimore Regional Planning Council. Therefore, the results in Table 3-4 indicate the order of magnitude of the expected influence of streambank erosion on estimated phosphorus flux.

3.4 CASE STUDY: SUSQUEHANNA RIVER BASIN

The phosphorus flux for the Susquehanna has also been studied. The Susquehanna Basin is more difficult to analyze than the Potomac because of a series of reservoirs on the river near its mouth which influence sediment and nutrient transport into the Chesapeake Bay and because the period of record for sediment discharge measurements for the stream is rather short.

Figure 3-2 is a map of the Susquehanna and indicates the nature of the seven subbasins into which the basin has been divided. The river drains an area of 27,580 sq miles. Table 3-5 gives data on the subbasins used.

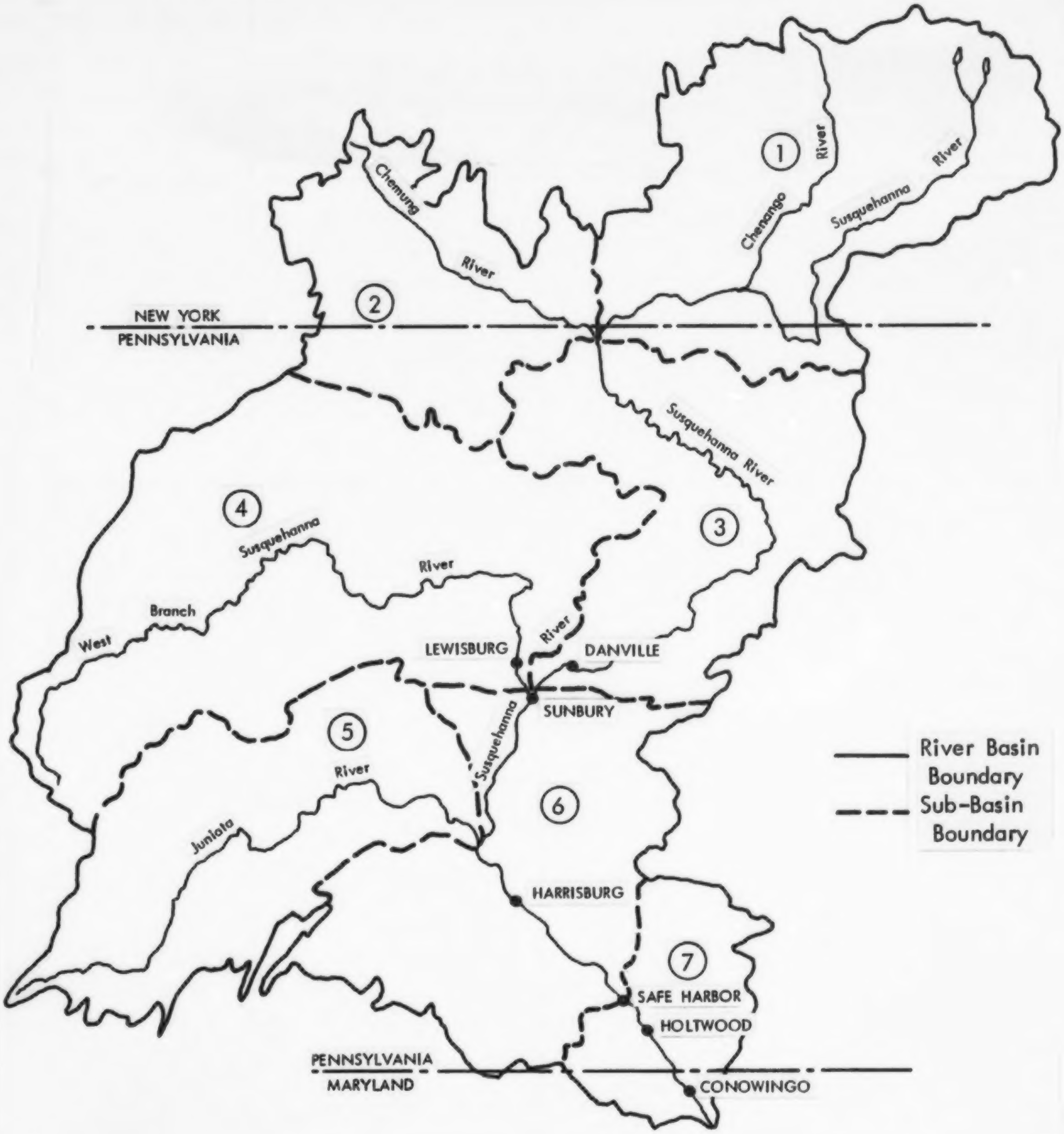
①
Chenango River
Susquehanna River
Chemung River
②
NEW YORK
PENNSYLVANIA
Susquehanna River
③
④
West Branch Susquehanna River
River
LEWISBURG
DANVILLE
SUNBURY
⑤
Juniata River
Susquehanna
⑥
HARRISBURG
⑦
SAFE HARBOR
HOLTWOOD
PENNSYLVANIA
MARYLAND
CONOWINGO
River Basin Boundary
Sub-Basin Boundary

Figure 3-2. Susquehanna River Basin.

TABLE 3-5. SUSQUEHANNA RIVER BASIN SUBWATERSHEDS

(1) Subbasin	(2) Inventoried area (miles^2)	(3) Soil loss (tons/yr x 10^{-6})	(4) Subbasin avg. soil phosphorus conc. (ppm)	(5) Avg. soil phosphorus loss (lb/acre/yr)	(6) Phosphorus loss (tons/yr x 10^{-3})
1 Susquehanna, above Athens, Pa.	4,720	4.7	510	1.6	2.4
2 Chemung River	2,540	3.2	500	2.0	1.6
3 Susquehanna, Athens, Pa. to Sunbury, Pa.	3,490	7.6	410	2.8	3.1
4 West branch Susquehanna	6,610	10.7	310	1.6	3.3
5 Juniata River	3,190	12.5	300	3.7	3.8
6 Susquehanna, Sunbury, Pa. to Safe Harbor Dam	4,010	25.9	340	6.9	8.9
7 Safe Harbor to mouth	1,100	7.6	460	9.8	3.5
Total	25,660	72.2			26.6

Calculations were done in the same manner as for the Potomac (see Appendix II for a discussion). Again, 1967 CNI data were used to represent land use. About 93% of the basin is inventoried. The noninventoried areas are urban land, small bodies of water, and federal land.

Suspended sediment discharge data are available at Harrisburg, Pennsylvania. The area drained above Harrisburg is 24,100 sq miles or 87% of the Susquehanna Basin. Data are available from only 1971 to the present so they cannot be classified as long term. Table 3-6 gives the annual sediment discharge information for Harrisburg. In 1972, the result of Hurricane Agnes was an unusually large sediment discharge from the basin.

TABLE 3-6. SUSPENDED SEDIMENT DISCHARGE AT HARRISBURG

Water year	Sediment discharge (tons)[a]
1971	1,418,761
1972	10,395,082
1973	3,603,250
1974	2,282,870
1975	3,976,008
1976	2,255,148
1977	3,426,936
Total	27,358,055 (16,962,973 without 1972)

[a] Source: Water Resources Data for Pennsylvania, Volume 2, Susquehanna and Potomac River Basins (Part 2, Water Quality Data), U.S. Geological Survey.

Neglecting the discharge for 1972 gives an annual average discharge of 2.83 x 10^6 tons/year at Harrisburg (6-year average).*

Williams and Reed (1972) have studied sediment yields in the Susquehanna Basin. Based on sediment yields in various portions of the basin, they estimate a total discharge of about 3 x 10^6 tons/year, neglecting trapping in reservoirs near the mouth of the river. Based on the work of Williams and Reed, the portion of the basin below Harrisburg but above Safe Harbor Dam (largely in the Lowland Piedmont) has an average sediment yield of about 200 tons/sq mile. Below Safe Harbor, the basin (in the Upland Piedmont) has an average sediment yield of about 300 tons/sq mile. Assuming that the sediment yield below Harrisburg and above Safe Harbor is 200 tons/sq mile, and using the estimated sediment discharge at Harrisburg given above, results in an estimate of 3.3 x 10^6 tons/year sediment discharge into the Safe Harbor reservoir.

The procedure outlined earlier and applied to the Potomac has been used to estimate a range of possible values for phosphorus flux into the Safe Harbor reservoir. Estimates have also been made for the phosphorus input into the Chesapeake Bay; however, the uncertainties involved are considerably increased.

From Table 3-5 the estimated soil loss above Safe Harbor is about 64.6 x 10^6 tons/year. The 3.3 x 10^6 tons/year estimate for sediment discharge therefore implies a delivery ratio of 0.051 for the portion of the basin above Safe

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* As was done for the Potomac, the contribution of bedload to sediment discharge was neglected for the Susquehanna. At Harrisburg the suspended sediment concentration is well below 1,000 mg/L even during high flow periods, and the suspended material is mostly silt and clay; less than about 10% is sand. The streambed is bedrock. Based on these considerations, the correction for bedload should be very small (Strand, 1975). The District Office of the U.S. Geological Survey in Harrisburg estimates that 5 to 10% of total load is bedload. Therefore, neglect of bedload for the river seems justified.

Harbor. Estimating sediment delivery to the Chesapeake Bay is more difficult because of the three dams near the mouth of the river: Safe Harbor, Holtwood, and Conowingo. Williams and Reed (1972) discuss the sediment trapping efficiencies of the reservoirs; therefore, some estimate of sediment delivery to the Bay can be made. However, it is difficult to assess the trapping effectiveness for nutrients, which would be expected to be less influenced by the reservoirs than is the sediment. A second complication is that the hurricane in 1972 resulted in sediment removal from the reservoirs, which may have altered their trapping efficiencies.

Minimum soil phosphorus concentrations for the Susquehanna are in subbasins 4 and 5, and maximum concentrations are in subbasins 1 and 2. Each of these subbasins has sufficient soil loss to satisfy the sediment discharge requirement at Safe Harbor (see Table 3-5). However, for either Subbasin 1 or 2, satisfying the sediment requirement would result in delivery ratios above 0.5; and, therefore, $\gamma r > 1.0$ (if $r = 2$). Hence, the maximum phosphorus flux must be determined by combining subbasins 1 and 2. The maximum and minimum phosphorus fluxes into the reservoir are the following (with $r = 2$).

$$\text{Maximum P flux} = \frac{3.3 \times 10^6}{7.9 \times 10^6} (4,000)(2) \text{ tons/year}$$

$$= 3,300 \text{ tons/year}$$

$$\text{Minimum P flux} = \frac{3.3 \times 10^6}{10.7 \times 10^6} (3,300)(2) \text{ tons/year}$$

$$= 2,000 \text{ tons/year}$$

where the calculations were made for subbasins 1 and 2 combined (maximum flux) and for subbasin 4 (minimum flux).

For a delivery efficiency for phosphorus equal to the basin average sediment delivery ratio, the phosphorus flux would be 2,400 tons/year. Table 3-7 summarizes phosphorus flux estimates at Safe Harbor.

TABLE 3-7. ESTIMATES OF AVERAGE ANNUAL PHOSPHORUS FLUX INTO RESERVOIR BEHIND SAFE HARBOR DAM

	Tons/yr
Upper limit equal to gross phosphorus loss above dam	23,100
Maximum flux with r = 2	3,300
Flux with basin average delivery ratio (0.051) and r = 2	2,400
Minimum flux with r = 2	2,000
Flux with basin average delivery ratio (0.051) and r = 1	1,200

Using the results of Williams and Reed (1972), an estimate can be made of sediment delivered to the Bay. For the purposes of these calculations, it will be assumed that the trapping efficiencies of the reservoirs are as given by Williams and Reed. If sediment removed from the reservoirs has increased their trapping effectiveness, then the results presented here are overestimates. Williams and Reed state that Safe Harbor reservoir is in a state of man-induced dynamic equilibrium with 10^6 tons of sediment deposited each year and the same amount being removed by dredging. They indicate that Holtwood has been in a state of dynamic equilibrium since the 1940's. Finally, they use a trapping efficiency of 17% for Conowingo Dam. To estimate sediment discharge at the mouth of the river, it will be assumed that the sediment yield in the area below Safe Harbor is 300 tons/sq mile/year and that all the material passes through or is deposited in Conowingo Reservoir. (Actually, some of the land is below Conowingo, but this consideration will be neglected.)

The area below Safe Harbor is estimated at 1,200 sq miles. Therefore, the sediment discharged from this area is:

$$(1,200)(300)(0.83) = 3.0 \times 10^5 \text{ tons/year}$$

The input to Safe Harbor is estimated at 3.3×10^6 tons/year. If 10^6 tons/year are removed at Safe Harbor and 17% of the remaining 2.3×10^6 tons/year are deposited in Conowingo, 1.9×10^6 tons/year reach Chesapeake Bay. To this must be added the contribution of 3.0×10^5 tons/year from below Safe Harbor, giving a total discharge to the Bay of 2.2×10^6 tons/year. (Williams and Reed estimate 1.8×10^6 tons/year.)

The sediment yield of 300 tons/sq mile/year assumed to apply below Safe Harbor is equivalent to a sediment delivery ratio of 0.047 for that subbasin. If phosphorus is delivered at this same efficiency (with $r = 2$), then the load added below Safe Harbor is 330 tons/year.

Since some portion of the phosphorus will be in a soluble form after reaching a stream and since the particulate phosphorus will be preferentially associated with smaller sized particles, there will be less relative loss of phosphorus in the reservoirs than there will be loss of sediment. The phosphorus downstream from each reservoir will be further enriched, but it is difficult to estimate this additional enrichment. However, if it is assumed that no phosphorus is lost in the reservoirs or if it is assumed that the loss is proportional to sediment loss, then upper and lower limits on phosphorus export may be obtained.

If phosphorus is unimpeded by the dams, then the maximum flux (with $r = 2$) at the mouth would be 3,300 + 330 = 3,600 tons/year. If phosphorus were trapped with the same efficiency as sediment, then about 30% of the input to Safe Harbor would be lost and about 17% of the phosphorus reaching Conowingo would be trapped. Since the minimum input to Safe Harbor (with $r = 2$) was estimated at 2,000 tons/year, 30% removal would leave 1,400 tons/year. Adding the 330 tons/year input below Safe Harbor and applying the 17% loss at Conowingo gives 1,400 tons/year to the Bay. Therefore, the input to the Bay should be in the range of 1,400 to 3,600 tons/year. Table 3-8 summarizes the results for the nonpoint loads of phosphorus reaching the Bay. The uncertainty in phosphorus flux for the Susquehanna is considerably larger than for the Potomac, primarily because of the difficulty of assessing how phosphorus will move through the reservoirs.

TABLE 3-8. ESTIMATES OF RURAL NONPOINT SOURCE FLUX OF PHOSPHORUS AT THE MOUTH OF THE SUSQUEHANNA

	Tons/yr
Upper limit equal to gross phosphorus loss in basin	26,600
Maximum flux (r = 2, no loss in reservoirs)	3,600
Minimum flux (r = 2, P follows sediment in reservoirs)	1,400
Flux using basin average delivery ratio (0.051) and r = 2	
No loss in reservoirs	2,700
P follows sediment in reservoirs	1,700

There are a number of impoundments and lakes in the upper portion of the Susquehanna Basin. However, these control a very small portion of the basin, about 700 sq miles of the 24,100 sq miles above Harrisburg. Their influence has been neglected.

As in the case of the Potomac, contributions of sediment from streambank and gully erosion have been neglected because of lack of data required to estimate their importance. The work by the Soil Conservation Service cited in the discussion of the Potomac suggests the magnitude of streambank erosion which might be expected in the lower portion of the Susquehanna. The phosphorus fluxes estimated here would be reduced in proportion to the contribution of sediment discharge arising from streambank erosion, again assuming negligible phosphorus input from that source. If the Soil Conservation Service results are indicative of conditions in the Susquehanna Basin, the influence of streambank erosion is small.

3.5 DISCUSSION

Minimum and maximum phosphorus fluxes were determined for both of the basins studied. These values should not be considered absolute upper and lower bounds on the fluxes. What the bounds do indicate, however, is the range of expected values if the assumptions used in the analysis are correct and if the various factors used were accurately estimated. It is worth considering how the results depend upon the factors involved in the analysis.

The important factors which must be known in order to carry out the analysis are: (a) the nutrient enrichment ratio, (b) the soil concentration of the nutrient, (c) the soil loss, and (d) the sediment discharge from the basin.

The flux estimate is directly proportional to all these except soil loss. Interestingly, the result is quite insensitive to uncertainties in the estimates of soil losses. The soil loss is involved in the analysis only to the extent that it determines the area of the basin needed to satisfy the sediment discharge requirement, which is important only if it should be near the size of the subbasins having maximum or minimum soil nutrient concentrations. For example, if the subbasin having maximum soil concentration had a small total soil loss, then it might be necessary to use the two (or more) subbasins with the highest soil concentrations of the nutrient to satisfy the sediment discharge requirement. Adding subbasins with lower soil concentrations would lower the maximum flux estimated. If the soil loss estimate were very inaccurate or if there were very large differences in soil nutrient concentrations between subbasins, this effect could become important. But it is not important for the basins studied here.

Therefore, the result is that the bounds that have been set on phosphorus flux are not sensitive to errors in the soil loss calculations. In addition, the results require no information on sediment delivery ratio. Hence, two of the most troublesome factors in the analysis play only minor roles in reaching the results. On the other hand, the results are quite sensitive to soil nutrient concentration, enrichment ratio, and sediment discharge. Knowledge of the last factor is based on field measurements, and the only assurance of a high level of accuracy is a substantial period of sampling. Nutrient concentration and enrichment ratio are quantities that would benefit from refinement.

An example of possible errors in the bounds given is the following. If soil loss estimates in the two basins are underestimates of any amount, then use of correct but larger values would have no influence on the result given. If the results are overestimated by as much as 40 to 50%, there is still no influence. Larger overestimates would result in decreases in the upper bounds given. Therefore, any conceivable uncertainties in soil loss calculations could do no more than decrease the upper bounds already set. If the enrichment ratios are in error by 25%, soil concentrations by 25%, and sediment discharge by 20%, the possible errors in the upper and lower limits would be about 90% and 55%, respectively. There is a possibility that some errors would be compensating and that errors in soil nutrient concentrations would not be uniform throughout the basin. Since the errors given for the various parameters are not unreasonable for the basins studied and for the analysis described here, they can be used to set rough limits on fluxes with uncertainties due to errors included.

The results given in Table 3-9 imply that the flux estimates are rather uncertain. This uncertainty is primarily due to the fact that the analysis used readily available data, and little effort at refinement was made. Considerable improvement would be expected if an effort were made to better evaluate the important parameters and to better define the possible errors in each.

The primary purpose of this work was to outline a methodology for assigning upper and lower limits to nutrient export from a watershed. The applications presented are not highly refined ones; in fact, they should only be viewed as a first step used to illustrate the approach. As indicated, are a number of ways in which the applications could be improved. Probably the most promising would be to use more refined values for phosphorus concentration in the soil.

TABLE 3-9. ESTIMATES OF AVERAGE ANNUAL PHOSPHORUS FLUXES[a]

	Tons/yr			
	Minimum flux		Maximum flux	
Location	Best estimate	Lower limit possible with errors	Best estimate	Upper limit possible with errors
Potomac at Great Falls	890	400	1,200	2,300
Susquehanna into reservoir behind Safe Harbor	2,000	900	3,300	6,200
Susquehanna at mouth				
No loss in reservoirs	-	-	3,600	6,800
P follows sediment in reservoirs	1,400	630	-	-

[a] Basis for calculations: Best estimates are taken from maximum and minimum flux values in Tables 3-3, 3-7, and 3-8. Upper and lower limits assume 25% errors in enrichment ratio and soil phosphorus concentration and a 20% error in sediment discharge and no compensation among errors. Results do not vary with errors in soil loss unless 40 to 50% over-estimates have been made (which would decrease maximum fluxes) and do not depend upon any underestimation of soil loss.

It would be very interesting to apply the methodology outlined here to a basin for which both long-term sediment and phosphorus yield data are available. If the basin were smaller than the one considered here, a more detailed analysis would also be possible.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

This report describes the application of a water quality screening methodology to a number of river basins of various sizes and characteristics. Volume I is concerned with the estimation of nonpoint source loads of pollutants in those basins. The primary goal of the application is to demonstrate an existing methodology, not to develop new techniques. Nevertheless, some small modifications and extensions to the existing approach have been made. The details of the application and the presentation of the modifications to the original methodology are presented in Chapters 2 and 3. There are a number of general issues related to the demonstration of the methodology which deserve additional attention or comments. These will be considered here.

4.1 DATA AVAILABILITY

Application of the methodology requires a large volume of data in spite of the relative simplicity of the overall approach. Therefore, a major problem in this study and probably in any other application is data availability. A screening analysis should by its nature not require the generation of significant quantities of data. Those data that are used in the analysis should already be available and should require a minimum of manipulation prior to use. For example, the Sandusky Basin has been well studied, but there was a definite lack of applicable data readily available for this study. Generally, the data which were available were aggregated to the county level, e.g., land use information. Also, as might be anticipated, in all the basins there was a problem in estimating sediment delivery ratios. Long-term sediment yield data are not available for the basins; therefore, average delivery ratios cannot be properly estimated. Furthermore, there is a lack of the sediment yield data needed to

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define variability within the basins. Finally, there is, generally, no way to estimate how average delivery ratios might vary with the season. Use of a single average value for the delivery ratio can result in a considerable over- or underestimation of loads for particular subbasins and seasons. This difficulty is nearly universal. It is, in fact, a problem of less concern in the Sandusky Basin than for most basins since some sediment measurements are available, and since the efficiency of delivery is thought to be relatively uniform throughout the basin. Information on pollutant loading rates and pollutant characteristics in urban areas is also not readily available. It was purely a matter of chance that actual measurements were available for use in one of the urban areas (Bucyrus) in one of the basins (Sandusky).

4.2 VALUE OF PARAMETER REFINEMENT

The most important parameter refinements involved land use data and the R, K, and C factors in the universal soil loss equation. The national data base used provides R values by Land Resource Area (LRA). These can easily be replaced by values which more nearly represent each county. Such values are available in Wischmeier and Smith (1978). For example, in the Sandusky, the change was from an annual value of 150 to 125. (Of course, individual event values were calculated for use in the demonstration.) Cover (C) factor values were also changed by the refinement process. The C values used for the individual counties reflect changes in the stage of crop growth, which is an improvement over the average annual C values in the data base. The level of resolution of soil erodibility values was improved from the LRA level (in the data base) to the county level. In some cases, resolution was at the subbasin level. As much as a 20 to 40% decrease in erodibility value was noted for some subbasins in the Sandusky due to refinements in the K values. Land use changes in that basin mostly increased soil loss in the interval between 1967 (data base) and the base year used in the individual basin calculations.

On balance then, as compared to the data base values, the refinements for the Sandusky led to decreases in R, K, and C and, therefore, to a decrease in annual soil loss over that which would be obtained using the data base. Land use changes partially offset the decrease. Again, using the Sandusky Basin as an example, in six out of the eight counties, average soil losses decreased by 20% or more due to the refinements. Given the level of effort required to produce the refinements and the inherent inaccuracy in the approach, the use of the data base is a very cost-effective approach. For annual soil loss calculations in the basins studied, the original data base will provide useful results (as compared to the refined values) if one merely modifies the R factors for each county and accounts for the major change in cropland. That is, a significant improvement is possible in this case with only a limited amount of effort.

Certain problems occurred in the attempt to improve the estimates for some of the parameters as already noted. A particular problem was estimating sediment delivery rates, a problem that was exacerbated in the case of individual subbasins. Reasonable estimates of delivery ratios are essential for accurate estimates of sediment delivered to a stream. Lacking a general approach to the problem, the delivery ratio issue will continue to frustrate many applications of the methodology. Although less difficult, problems also occurred with other parameters as well. The LS and the P factors in the USLE were not modified and were used directly from the existing national data base. Improvement of the estimates used requires substantial information on topography and soil conservation practices in each basin. As already noted, data on the loading rates for pollutants on city streets are generally lacking and recourse must be made to tabulated, crude averages.

4.3 SENSITIVITY ANALYSIS

A screening methodology such as is being considered in this study involves numerous simplifications and assumptions. In the case of urban nonpoint loads, the important matter of sensitivity to assumptions was considered in section 2.1.4.3. As noted, the major problem centers on determination of street loading rates and use of an annual average approach. Rural nonpoint loads have not yet been discussed from the point of view of sensitivity to the various factors involved in the analysis. The most important fact to recall in the case of rural nonpoint sources is that the various factors used in determining sediment or nutrient loads (except rainfall inputs) are multiplied together to obtain the final result. Therefore, uncertainties in the factors are multiplied. For example, for sediment loads, a 20% error in each factor involved in determining the load gives approximately a 300% error in the load, assuming no compensation among the errors. Similar errors in the case of nutrient calculation yield a total error of about 400%. Since most of the factors cannot be determined with an error of less than 20%, the possible error in the results can be quite large unless there is compensation among the errors. This fact indicates that the results obtained are always rather uncertain.

Uncertainties in land use information in the present application relate primarily to the resolution of the information. Agricultural land use data are generally available; however, they are at the county level of resolution. Therefore, specifying land use conditions in a subbasin may be difficult. The primary need in land use data is for accurate specification of the cropland--its area and type of crop. Land use affects pollutant load calculations through the C factor in the USLE. In an application in which a pollutant load is needed for a subbasin which covers a fraction of a county and in which land use and other data are available only at the county level of resolution or lower, the loads may be grossly overestimated. This could occur in a subbasin for which a higher than average fraction (for the county) is cropped, for which slopes are steeper than average, or for which there are no conservation practices applied ($P = 1$). Poor resolution of needed data can result in substantial errors for particular locations within a basin.

Results are also somewhat sensitive to errors in describing agricultural practices in a basin. The significance of errors in practices relates primarily to the problem of timing of agricultural operations and, therefore, the degree of cover on the ground at particular times.

In summary, errors in results are directly proportional to errors in the various parameters used in the analysis since they are multiplicative. Assessment of sensitivity to errors in the description of practices or land use, or to the degree of resolution in the available data is an involved exercise which will yield results that vary considerably from basin to basin. Such variability is anticipated because of different rainfall patterns and the degree of homogeneity of land use among basins.

4.4 LEVEL OF EFFORT REQUIRED IN AN APPLICATION

Application of the nonpoint load estimation methodology to basins such as those examined in this study should require on the order of two to three person weeks of effort per basin. This estimate assumes an analyst familar with the procedure and with the general subject of rural nonpoint source loads. It also assumes familiarity with use of the nonpoint calculator program. The availability and use of more extensive data than considered in this demonstration would increase the time required. Report preparation is not included in the time estimate.

4.5 VERIFICATION OF THE LOAD ESTIMATION PROCEDURES

Considering the lack of measured nonpoint loads (both rural and urban) available for comparison and the long-term average nature of the estimates which have been made, verification of the procedure by direct comparison with measured loads is quite difficult. Comparison with measured instream concentrations is a more promising approach. The results presented in Volume II indicate the level of verification that can be expected for the approach used, particularly in the case of the Sandusky Basin.

4.6 FUTURE APPLICATIONS

In the present study, considerable effort was expended in selecting a series of events for each basin so that consistent flow data were available for use in the instream assessment. This was necessary to assure compatibility and to allow an attempt at verification of the results. In actual applications, such a selection of actual events may be unnecessary. A possible approach would be to define typical average events for various stages in cover occurring throughtout the year. These "typical" events could be equivalent to events that produce some fraction of the total soil loss which occurs during some fraction of the year. The information needed to define such an event is available in terms of the annual distribution of the R factor. Such distributions are tabulated in Wischmeier and Smith (1978) or may be constructed. Wischmeier and Smith also provide tables on the magnitude of R for single storms having various recurrence intervals at different locations. Therefore, in an application it is possible to consider design storms with characteristics that can be defined independently of an actual watershed.

4.7 USE OF THE LOAD ESTIMATION METHODOLOGY IN SPECIALIZED APPLICATIONS

Chapter 3 provides an example of the application of much of the basic rural nonpoint source methodology to the problem of estimating long-term nutrient fluxes in streams. This application shows that the procedures can be applied in ways which overcome some of their fundamental weaknesses (e.g., the need for a delivery ratio), while providing useful results. It is likely that other specialized applications can be developed also.

4.8 ATTAINMENT OF THE GOALS OF THE STUDY

The primary goal of the study was to demonstrate the methodology under actual field condition. This goal has been accomplished, and most of the issued discussed in this chapter have related to this demonstration. The nonpoint loading procedures and the 208 screening methodology have also been shown to be compatible which was one of the subgoals of the program.

The application points out the primary strengths of the methodology, its relative simplicity and the ease with which basic calculations can be done and its weaknesses--dependence on a delivery ratio, a higher level of spatial aggregation in the case of practical applications in large basins, and the need for large amounts of data. These characteristics are well demonstrated in the studies of the various basins, which illustrate the degrees of data availability likely in practice. As indicated above, these applications indicate that major parameter refinements tend to be time consuming and, in many cases, of limited value. They also indicate the difficulty of determining or assigning sediment delivery ratios in most cases.

4.9 IMPACT OF METHODOLOGICAL SHORTCOMINGS ON AN ASSESSMENT

There are several important features in the rural nonpoint methodology which limit the accuracy that can be expected from the results of an assessment. These features include: (a) a high level of spatial aggregation in the analysis--an important fact since the USLE is intended for rather small, homogeneous areas; (b) the use of a delivery ratio to account for sediment transport; (c) the assumption that pollutants such as phosphorus are associated with sediment; and (d) the long-term average, nonhydrologic nature of the USLE.

An attempt was made to overcome the lack of suitability of the USLE for analyzing actual events by averaging over many events. Dealing with an average event in this manner is acceptable; however, proper averaging requires many events occurring over a long period of time. Data are not always available to carryout such averaging.

Additional shortcomings occur in the urban methodology used, which deals with annual loads and which depends upon street loading rates that are not well established.

A screening methodology such as was applied here is intended for relatively easy application using existing data. Overcoming some of the limitations listed above would require greatly increased amounts of data to reduce spatial resolution problems, to provide increased information on sediment transport, and to provide data on runoff needed to allow soluble forms of constituents to be included and to allow a more hydrologically based approach. Since this demonstration illustrates the fact that needed data may not be available even for the screening approach used, it seems reasonable to conclude that more rigorous approaches can result in even more obstacles due to data limitations, especially when large areas must be considered.

The users of the nonpoint methodology should be well aware of its limitations. However, these limitations should not prevent the use of the approach. As the present study shows, applications can be made which result in useful inputs to water quality assessments in spite of certain methodological shortcomings of the procedures used. The user should always recall that the methodology is intended for screening purposes.

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APPENDIX I - P FACTORS, SLOPES, AND SLOPE LENGTHS USED IN CHAPTER 2

In the tables which follow, practice factors (P) and slopes and slope lengths are tabulated for the regions considered in the demonstrations in Chapter 2.

The practice factors were developed based on information in State Conservation Needs Inventories. Practice factors are given as a function of land use and capability class for each county. See Table 2-11 for definitions of these uses and classes.

Slopes and slope lengths were provided to MRI by the Soil Conservation Service. Slopes are given in percent and slope lengths in feet. These quantities are tabulated by Land Resource Areas (LRAs) in the following displays. Within each LRA, they are given as a function of land capability class.

The slope and slope length factors (S and L) can be determined for the slopes and lengths as follows (Wischmeier and Smith, 1978):

$$S = (0.056 + 4.56s + 65.41s^2)$$

where s = field slope in percent

and $$LS = S \frac{\lambda}{72.6}^{m}$$

where λ = slope length in feet

and $m = 0.2$ for gradients $< 1\%$
$m = 0.3$ for 1 to 3% slopes
$m = 0.4$ for 3.5 to 4.5% slopes
$m = 0.5$ for 5% slopes and steeper

Reference: Wischmeier, W. H., and D. D. Smith, Predicting Rainfall Erosion Losses - A Guide to Conservation Planning, U.S. Department of Agriculture, Agriculture Handbook No. 537, 1978.

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TABLE I-1. PRACTICE FACTORS BY LAND USE AND LAND CAPABILITY CLASS FOR EACH COUNTY

Kent County DE

Practice Factor (x100)

LCC \ LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	78	78	78	0	78	78	78	0	50	50	100	0	60	0	89	0
2	89	89	89	89	89	89	89	0	56	63	75	0	60	0	89	0
3	87	87	87	0	87	87	87	0	0	0	0	0	60	0	89	0
4	85	85	85	85	85	85	85	0	0	50	100	0	60	0	89	0
6	86	86	86	0	0	0	0	0	0	0	0	0	0	0	89	0
7	89	89	0	0	0	0	89	0	0	0	0	0	0	0	89	0
8	95	95	95	0	95	95	95	0	0	53	100	0	0	0	89	0
10	100	0	0	0	0	0	0	0	0	0	0	0	0	0	89	0
20	100	0	0	0	0	0	0	0	0	0	0	0	0	0	89	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0

New Castle County DE

Practice Factor (x100)

LCC \ LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	70	70	70	0	70	0	0	70	0	50	75	0	64	0	93	0
2	89	89	89	0	89	89	89	89	75	67	77	0	64	75	93	50
3	0	0	75	0	0	0	0	0	0	0	0	0	0	0	0	0
4	69	69	0	0	69	69	0	0	0	50	100	0	64	0	93	0
6	86	0	86	0	86	86	0	0	0	50	77	0	64	75	93	0
8	85	85	85	0	85	85	85	0	50	50	100	0	64	75	93	50
10	66	66	66	0	0	66	0	0	50	77	0	64	75	93	50	50
16	0	0	0	0	0	0	0	50	0	75	0	0	0	0	93	0
18	79	0	79	0	79	79	0	0	0	83	75	0	64	0	93	50
20	100	0	0	0	0	0	0	0	0	0	100	0	64	75	93	0
23	0	0	0	0	0	0	0	0	0	50	0	0	0	0	93	0
27	0	0	0	0	0	0	0	0	0	70	0	0	0	75	0	0
28	0	100	0	0	0	0	0	0	0	50	0	0	64	75	93	50

(continued)

TABLE I-1. (continued)

Anne Arundel County MD

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	70	70	0	0	70	0	70	0	0	0	0	0	0	57	93	0
2	86	86	86	0	86	86	86	70	0	56	90	0	67	57	93	0
3	92	92	92	0	92	0	92	92	0	0	0	0	0	57	93	0
4	91	91	0	0	0	0	91	91	100	0	92	0	67	57	93	0
6	83	83	83	0	0	83	0	83	0	0	90	0	0	57	93	0
7	100	0	0	0	0	0	0	0	0	0	0	0	0	57	93	0
8	100	100	100	0	0	0	100	0	0	0	92	0	67	57	93	0
10	83	83	83	0	83	83	83	83	0	0	90	0	67	57	93	0
11	0	66	0	0	0		66	66	0	63	100	0	67	57	93	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	0
18	84	84	84	0	84	84	84	84	0	61	100	0	0	57	93	0
20	0	0	0	0	0	0	50	0	0	0	0	0	0	0	93	0
22	0	75	0	0	0	75	0	75	0	0	100	0	0	57	93	0
23	0	0	0	0	0	0	100	0	0	65	0	0	0	57	93	0
24	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	57	93	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	57	93	0

Calvert County MD

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	58	58	58	0	0	58	0	0	0	77	0	0	72	0	0	0
2	78	78	78	0	78	78	78	0	60	0	85	0	0	71	94	0
3	0	92	0	0	0	0	0	0	0	0	0	0	0	0	94	0
4	50	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0
6	97	97	97	0	97	97	97	97	0	0	85	0	0	0	94	0
7	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	50	0	0	0	50	0	0	0	0	0	0	0	0	0	94	0
10	91	91	0	0	91	91	91	91	0	0	85	0	72	71	94	79
11	0	89	0	0	0	0	0	89	0	0	0	0	72	0	94	0
18	98	98	98	0	98	98	0	0	0	0	89	0	0	0	94	0
19	0	100	0	0	100	0	0	0	0	0	0	0	0	0	94	0
20	0	0	0	0	0	0	0	0	0	0	0	0	72	0	94	0
22	0	94	94	0	0	94	94	0	0	0	89	0	0	0	94	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94	0
28	0	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0

(continued)

TABLE I-1. (continued)

Charles County MD

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	96	96	0	0	0	0	96	0	0	0	0	0	0	57	93	0
2	94	94	94	0	94	94	94	94	0	100	100	0	60	57	93	0
3	0	58	0	0	0	0	58	0	0	50	0	0	60	57	93	0
4	92	92	92	0	0	0	92	92	73	0	86	0	0	57	93	0
6	100	100	100	0	0	0	0	100	0	100	100	0	0	57	93	0
8	93	93	93	0	0	0	93	93	0	0	86	0	60	57	93	0
10	79	79	0	0	79	0	79	79	0	83	100	0	0	0	93	0
11	100	100	0	0	0	0	00	100	0	100	100	0	0	57	93	0
12	96	96	0	0	96	0	0	96	0	100	0	0	60	57	93	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	0
18	89	89	89	0	89	0	89	89	0	0	0	0	60	0	93	0
20	0	0	0	0	0	0	75	75	0	0	0	0	0	0	93	0
22	80	0	0	0	0	0	0	0	0	0	100	0	60	57	93	0
23	100	100	100	0	0	0	100	100	0	0	100	0	0	0	93	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	0
28	0	0	0	0	0	0	0	0	0	0	0	0	60	57	93	0

Howard County MD

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	50	50	50	0	0	50	0	0	0	0	83	0	59	0	86	0
2	79	79	79	0	79	79	79	0	0	100	80	0	59	55	86	55
3	0	67	0	0	0	0	0	0	0	0	100	0	59	0	86	0
4	79	79	79	0	0	79	0	0	57	0	69	0	59	0	86	55
6	77	77	77	0	0	77	77	0	0	50	80	0	59	55	86	55
7	0	86	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	63	63	0	0	0	0	0	0	0	50	69	0	0	0	86	55
10	83	83	83	0	0	83	83	83	0	100	80	0	59	55	86	55
11	0	92	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	57	0	69	0	0	0	86	0
16	0	0	0	0	0	50	0	0	0	0	78	0	0	0	86	55
18	68	68	68	0	0	68	0	0	0	83	86	0	0	55	86	55
19	0	79	0	0	0	0	0	0	0	0	0	0	0	0	86	0
20	0	0	0	0	0	0	0	0	0	0	78	0	0	0	86	0
22	59	59	59	0	0	59	59	0	0	0	86	0	59	0	86	55
23	0	91	0	0	0	0	0	0	0	0	0	0	0	0	86	55
27	0	0	0	0	0	0	0	0	0	0	0	0	59	55	0	0

(continued)

TABLE I-1. (continued)

Kent County MD

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	51	51	51	0	51	51	0	51	0	0	0	0	58	0	94	0
2	92	92	92	0	92	92	92	0	0	68	81	0	58	62	94	57
4	95	95	0	95	0	95	95	0	93	81	0	58	62	94	57	57
6	94	94	94	0	94	94	0	94	0	0	81	0	58	62	94	57
7	92	92	0	0	0	92	0	0	0	0	100	0	0	0	0	0
8	97	97	97	0	97	0	0	0	50	0	81	0	58	62	94	0
10	88	88	88	0	88	88	0	0	0	0	0	0	58	0	94	0
18	93	0	0	0	93	93	0	0	0	0	100	0	58	0	94	0
20	0	0	100	0	0	0	0	0	0	0	0	0	58	0	94	0
23	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0

Montgomery County MD

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	55	0	55	0	0	0	0	0	0	0	0	0	0	75	93	0
2	79	0	79	0	79	79	79	55	50	81	0	55	75	93	56	56
3	0	0	78	0	78	0	0	78	0	50	0	0	0	0	93	56
4	73	0	73	0	73	73	0	73	0	50	89	0	55	75	93	56
6	79	79	79	0	79	79	79	79	0	54	81	0	55	75	93	56
8	100	0	0	0	0	0	0	0	0	0	89	0	0	0	93	0
10	81	0	81	0	81	81	81	81	0	61	81	0	55	75	93	56
12	0	0	0	0	0	50	0	50	0	50	89	0	55	75	93	56
16	0	0	100	0	0	0	0	0	0	0	88	0	0	75	93	56
18	98	0	98	0	98	0	0	0	0	78	89	0	0	75	93	56
19	0	0	0	0	0	0	0	0	0	0	0	0	0	93	56	56
20	0	0	0	0	0	0	0	0	0	0	0	0	0	75	93	0
22	88	0	88	0	88	88	0	88	0	61	89	0	55	75	93	56
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	56

(continued)

TABLE I-1. (continued)

Prince Georges County MD

Practice Factor (x100)

LCC \ LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	57	57	0	0	0	0	0	0	0	100	100	0	0	0	98	0
2	85	85	85	0	85	85	85	85	50	83	67	0	87	86	98	80
3	93	93	93	0	0	93	0	0	0	60	0	0	87	86	98	80
4	85	85	0	0	0	85	0	0	0	83	0	0	87	86	98	80
6	92	92	92	0	92	92	92	0	0	90	67	0	87	0	98	80
7	90	90	0	0	0	0	0	0	0	0	100	0	87	86	98	0
8	90	90	0	0	90	0	0	0	0	100	100	0	87	0	98	80
10	93	93	93	0	93	93	93	0	0	82	67	0	87	86	98	80
11	87	87	0	0	0	0	0	0	0	0	0	0	87	0	98	80
12	100	0	0	0	0	0	0	0	0	0	0	0	87	0	98	80
18	96	96	96	0	96	96	0	96	0	80	86	0	87	0	98	80
19	93	93	93	0	93	0	0	0	0	100	100	0	87	86	98	80
20	0	0	0	0	0	0	0	0	0	0	0	0	87	0	98	80
22	93	93	0	0	0	93	93	0	0	100	86	0	0	86	98	80
23	0	100	0	0	0	0	0	0	0	0	0	0	0	86	98	80
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	80
27	0	0	0	0	0	0	0	0	0	0	0	0	87	86	98	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	0

Queen Annes County MD

Practice Factor (x100)

LCC \ LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	63	63	63	0	63	0	63	63	0	0	0	0	52	0	94	0
2	69	69	69	0	69	69	69	69	50	0	84	0	52	61	94	0
3	78	0	78	0	0	0	0	0	0	0	0	0	52	0	0	0
4	85	85	85	0	85	0	85	0	0	0	0	0	52	61	94	0
6	72	72	72	0	72	72	0	0	94	0	0	52	0	94	0	0
8	97	97	97	0	97	0	97	0	0	0	0	0	52	0	94	0
10	69	0	69	0	69	0	0	0	0	0	0	0	52	0	0	0
18	0	0	0	0	50	0	0	0	0	0	0	0	52	0	94	0
20	83	83	0	0	0	0	0	0	0	0	0	0	52	0	94	0
22	68	0	0	0	68	0	68	0	0	0	0	0	52	0	94	0
28	0	0	0	0	0	0	0	0	0	0	0	0	52	0	94	0

(continued)

TABLE I-1. (continued)

St Marys County MD

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	62	62	0	0	0	0	0	0	0	0	50	0	0	56	96	0
2	81	81	81	0	81	81	81	81	0	71	66	0	55	56	96	95
3	84	84	84	0	0	84	0	84	0	0	100	0	55	0	96	0
4	89	89	89	0	0	0	89	89	0	50	84	0	55	56	96	0
6	92	92	0	0	0	0	0	92	0	0	66	0	0	0	96	0
7	0	87	0	0	0	0	0	87	0	0	0	0	0	0	0	0
8	89	89	89	0	0	0	0	89	53	0	84	0	55	56	96	95
10	89	89	89	0	89	89	0	0	0	75	66	0	0	56	96	95
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0
18	91	91	91	91	0	91	0	91	0	50	100	0	55	56	96	95
22	0	0	0	0	0	0	0	0	0	0	0	0	55	56	96	0
23	0	0	0	0	0	0	0	93	0	0	0	0	0	56	96	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	56	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0

Crawford County OH

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	69	69	69	0	69	0	69	0	50	0	79	0	60	0	90	0
2	63	63	63	0	63	0	63	0	0	0	77	0	60	60	90	0
4	91	91	91	0	91	91	91	0	0	0	74	0	60	60	90	0
6	98	98	98	0	98	0	98	0	0	0	77	0	60	60	90	0
8	100	100	100	0	100	0	100	0	0	0	74	0	60	60	90	0
10	100	100	100	0	100	0	100	0	50	0	0	0	60	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0
18	0	100	0	0	100	0	0	0	0	0	70	0	60	0	90	0

(continued)

TABLE I-1. (continued)

Hardin County OH

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0	0	0	0	0	0	50	0	0	0	90	0
2	60	60	60	0	60	0	60	0	0	0	59	0	58	0	90	0
3	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0
4	85	85	85	0	85	0	85	85	0	0	56	0	58	54	90	0
6	79	79	79	0	79	0	79	79	0	0	59	0	58	0	90	0
8	76	76	76	0	76	0	76	0	0	0	56	0	58	54	90	0
10	100	100	0	0	0	0	0	0	0	0	59	0	0	0	0	0

Huron County OH

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	50	50	50	0	0	0	50	50	0	50	100	0	57	0	90	0
2	56	56	56	0	56	0	56	0	0	0	80	0	57	53	90	0
3	91	91	91	0	91	0	0	0	0	0	0	0	0	0	90	0
4	100	100	100	0	100	0	100	100	55	100	83	0	57	53	90	50
6	69	69	69	0	69	0	69	0	0	100	80	0	57	0	90	0
8	94	94	94	0	94	0	94	94	0	0	83	0	57	53	90	0
10	100	100	100	0	100	0	0	0	0	0	80	0	0	0	90	0
11	100	0	100	0	0	0	0	0	0	0	0	0	57	0	0	0
12	94	94	94	0	94	0	94	94	0	0	83	0	57	0	90	0
18	100	0	0	0	0	0	0	0	0	0	100	0	57	0	90	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0

Marion County OH

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	100	100	0	0	0	0	100	0	0	0	0	0	0	0	92	0
2	100	100	100	0	100	0	100	0	50	100	69	0	51	0	92	0
4	93	93	93	0	93	0	93	93	0	66	62	0	51	51	92	0
6	0	100	100	0	100	0	100	0	50	0	69	0	51	0	92	0
8	100	100	100	0	100	0	100	0	0	100	62	0	51	0	92	0
10	0	100	0	0	0	0	100	0	0	100	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92	0

(continued)

TABLE I-1. (continued)

Richland County OH

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	68	68	68	0	68	68	68	68	0	0	100	0	60	0	90	0
2	73	73	73	0	73	73	73	73	0	0	95	0	60	60	90	0
3	0	50	0	0	0	0	0	0	0	50	0	0	0	60	0	0
4	88	88	88	0	88	88	88	88	0	50	84	0	60	60	90	0
6	78	78	78	0	78	78	78	0	50	0	95	0	60	60	90	0
8	100	100	0	0	100	0	0	0	0	50	84	0	0	60	90	0
10	69	69	69	0	69	69	69	69	50	0	95	0	60	60	90	0
18	0	0	67	0	0	67	67	0	50	0	100	0	0	0	90	0
22	0	0	0	0	0	50	50	0	0	0	0	0	0	0	90	0

Sandusky County OH

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	94	94	94	0	94	0	0	94	0	0	0	0	0	0	90	0
2	76	76	76	0	76	0	76	76	0	0	50	0	0	51	90	0
3	97	97	97	0	0	0	0	97	50	0	0	0	0	51	0	0
4	81	81	81	0	81	0	81	81	65	0	71	0	53	51	90	0
6	96	96	96	0	96	0	96	96	0	0	50	0	0	0	90	0
7	74	74	74	0	0	0	74	74	0	0	50	0	53	51	90	0
8	84	84	84	0	84	0	84	84	50	0	71	0	53	51	90	0
10	100	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0
11	82	82	82	0	82	0	82	82	0	0	50	0	53	51	0	0
12	81	0	81	0	81	0	81	0	0	0	0	0	0	0	90	0
19	100	0	100	0	0	0	0	0	0	0	50	0	53	0	90	0
22	50	0	50	0	0	0	0	0	0	0	0	0	0	51	90	0

(continued)

TABLE I-1. (continued)

Seneca County OH

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	84	84	84	0	84	0	0	0	0	0	91	0	58	0	89	0
2	53	53	53	0	53	0	53	53	0	0	91	0	58	58	89	0
3	84	84	84	0	84	0	84	0	0	0	91	0	58	58	89	0
4	90	90	90	0	90	0	90	90	0	0	91	0	58	58	89	0
6	100	100	100	0	100	0	100	0	50	0	91	0	58	0	89	0
7	64	64	64	0	64	0	0	0	0	0	91	0	0	0	89	0
8	82	82	82	0	82	0	82	0	0	0	91	0	58	0	89	0
10	0	100	100	0	100	0	100	0	0	0	91	0	0	0	89	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0
18	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89	0
22	0	0	0	0	0	0	0	0	0	0	91	0	0	0	89	0

Wyandot County OH

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	60	60	60	0	0	0	0	60	0	0	63	0	0	0	93	0
2	52	52	52	0	52	52	52	52	0	0	91	0	63	0	93	0
3	0	0	100	0	0	0	0	0	0	0	100	0	0	55	0	0
4	90	90	90	0	90	90	90	90	0	100	62	0	63	0	93	0
6	69	69	69	0	69	0	69	69	50	50	91	0	63	0	93	0
8	90	90	90	0	90	0	90	90	0	100	62	0	63	55	93	0
10	83	83	83	0	83	83	83	83	0	0	91	0	63	0	93	0
11	0	100	0	0	0	0	0	0	0	0	0	0	0	0	93	0
18	0	100	100	0	0	0	50	0	0	0	57	0	63	0	93	0
22	0	100	0	0	0	0	0	0	0	0	57	0	0	0	93	0

(continued)

TABLE I-1. (continued)

Fairfax County VA

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	75	0	75	0	0	0	0	0	100	0	0	65	0	50
2	0	0	94	0	94	0	0	0	100	0	84	0	60	65	64	50
4	60	60	60	0	60	0	0	0	0	0	93	0	60	65	64	50
6	87	0	87	0	87	0	0	87	0	0	84	0	60	65	64	50
7	0	0	0	0	100	0	0	0	0	0	90	0	0	65	64	0
8	0	0	100	0	100	0	0	0	0	0	93	0	0	65	64	50
10	0	0	0	0	0	0	0	0	0	0	84	0	60	65	64	50
11	0	0	0	0	0	0	0	0	0	0	0	0	60	0	64	0
12	0	0	0	0	100	0	0	0	0	0	93	0	0	0	64	50
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0
18	0	0	58	0	0	0	58	0	0	0	100	0	60	65	64	50
19	0	0	0	0	100	0	0	0	0	0	100	0	0	0	64	0
20	0	0	0	0	0	0	0	0	0	0	100	0	0	65	64	50
22	0	0	83	0	83	0	0	0	0	0	100	0	0	65	64	50
23	0	0	0	0	0	0	0	0	0	0	0	0	60	0	64	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	65	0	50

Fauquier County VA

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	59	0	59	0	59	59	0	0	0	0	81	0	68	0	0	0
2	85	0	85	0	85	85	85	0	0	0	79	0	68	73	64	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0
4	0	0	0	0	50	0	0	0	0	0	80	0	68	0	64	0
6	87	0	87	0	87	87	87	87	0	62	79	0	68	73	64	0
7	0	0	0	0	0	50	0	0	0	0	79	0	0	0	64	0
8	85	0	85	0	85	85	0	0	0	0	80	0	68	73	64	0
10	80	0	80	0	80	80	80	0	0	0	79	0	68	73	64	0
11	0	0	0	0	0	0	0	0	0	0	79	0	0	73	64	0
12	69	0	69	0	69	69	69	0	0	0	80	0	68	73	64	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0
18	100	0	100	0	100	100	0	100	0	0	78	0	68	73	64	0
19	100	0	0	0	100	0	0	0	0	0	0	0	0	0	64	0
20	100	0	100	0	100	0	0	0	0	0	77	0	0	0	64	0
22	82	0	82	0	82	82	82	0	0	0	78	0	68	73	64	0
23	68	0	0	0	68	68	68	0	92	0	82	0	68	73	64	0

(continued)

TABLE I-1. (continued)

Gloucester County VA

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	70	0	0	70	70	0	0	50	0	90	0	56	0	76	0
2	72	72	72	0	72	72	72	0	61	0	90	0	56	0	76	0
3	80	80	80	0	80	80	80	80	50	0	90	0	56	0	76	0
4	90	90	90	0	90	90	90	90	58	75	88	0	56	73	76	0
6	0	84	0	0	84	0	0	0	50	0	0	0	0	0	76	0
7	80	80	80	0	80	80	80	80	56	75	0	0	56	0	76	0
8	88	88	88	0	88	88	88	88	67	0	88	0	56	73	76	0
10	0	0	0	0	79	79	79	0	100	0	90	0	0	0	76	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	0
20	0	0	0	0	0	0	0	0	0	0	0	0	56	0	76	0
22	0	0	0	0	100	100	100	0	0	0	94	0	0	0	76	0
24	0	0	0	0	0	0	0	0	0	0	100	0	56	0	76	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0

Loudoun County VA

Practice Factor (x100)

LU= LCC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	78	0	78	0	78	0	78	78	0	50	79	0	0	70	0	0
2	79	0	79	0	79	79	79	79	50	50	83	0	69	70	74	54
3	0	0	0	0	0	0	0	0	0	0	0	0	0	70	74	0
4	86	0	86	0	86	0	0	0	0	50	94	0	0	70	74	0
6	89	0	89	0	89	0	89	89	50	50	83	0	69	70	74	54
7	72	0	72	0	72	72	72	72	0	0	83	0	69	70	74	54
8	85	0	85	0	85	85	85	85	0	50	94	0	69	70	74	54
10	88	0	88	0	88	88	88	88	0	95	83	0	69	70	74	54
11	64	0	64	0	64	64	64	0	0	50	83	0	0	70	74	0
12	64	0	64	0	64	0	64	0	0	50	94	0	69	70	74	54
16	74	0	74	0	74	0	74	0	0	0	91	0	69	70	74	54
18	83	0	83	0	83	0	83	0	100	0	91	0	69	70	74	54
19	0	0	67	0	67	0	67	0	73	0	88	0	69	70	74	54
22	0	0	83	0	83	0	0	0	0	0	91	0	69	70	74	54
23	78	0	78	0	78	0	78	0	0	100	88	0	69	70	74	54

(continued)

TABLE I-1. (continued)

Prince William County VA

Practice Factor (x100)

LU=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LCC																
1	0	0	0	0	0	50	0	0	0	0	83	0	74	72	0	0
2	71	0	0	0	0	71	71	71	0	83	86	0	74	72	74	50
4	0	97	0	0	97	97	97	97	0	50	84	0	0	72	74	50
6	85	0	0	0	85	85	85	85	0	88	86	0	74	72	74	50
7	0	0	0	0	0	50	0	0	0	0	50	0	0	72	74	50
8	0	0	100	0	0	100	0	0	0	0	84	0	0	72	74	0
10	66	0	0	0	0	66	66	66	0	0	86	0	74	72	74	50
11	0	0	0	0	50	50	50	0	0	0	0	0	0	72	74	0
12	0	0	0	0	0	100	100	0	0	50	84	0	0	72	74	0
16	0	0	0	0	0	0	0	0	0	0	93	0	0	72	74	0
18	0	0	0	0	100	100	0	0	0	0	75	0	0	0	74	50
19	0	0	0	0	0	0	50	0	0	0	0	0	0	0	74	50
22	100	0	0	0	0	0	0	0	0	0	0	0	0	74	50	50
23	50	0	0	0	0	50	50	0	0	0	100	0	0	0	74	50
24	0	0	0	0	0	0	100	0	0	0	0	0	0	0	74	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	72	0	0

TABLE I-2. SLOPE LENGTH IN LAND RESOURCE AREA BY LAND CAPABILITY CLASS

LCC	LRA=	Slope length (ft)				
		99	111	148	149	153
1		200	400	586	586	650
2		200	150	250	600	300
3		300	300	518	400	700
4		200	400	518	700	600
5		300	333	518	633	633
6		175	200	250	300	200
7		300	333	518	633	633
8		400	300	518	800	600
9		300	333	518	633	633
10		150	200	200	500	100
11		250	200	150	600	600
12		250	200	150	800	600
13		250	200	150	700	600
14		145	191	230	380	200
15		250	200	150	700	600
16		250	200	150	700	600
17		250	200	150	700	600
18		100	175	150	300	200
19		250	150	200	800	150
20		225	125	275	800	150
21		225	125	275	800	150
22		100	230	300	200	200
23		225	125	275	800	150
24		200	100	350	800	200
25		225	125	275	800	150
26		145	191	230	380	200
27		225	125	275	800	150
28		225	125	275	800	100
29		225	125	275	800	150

TABLE I-3. SLOPE IN LAND RESOURCE AREA BY LAND CAPABILITY CLASS

		Slope (%)				
LCC	LRA=	99	111	148	149	153
1		1.0	1.0	1.0	1.0	1.0
2		4.0	4.0	5.0	3.0	3.0
3		1.0	1.0	1.6	2.0	1.0
4		1.0	1.0	1.6	2.0	4.0
5		1.0	1.0	1.6	2.0	2.7
6		9.0	8.0	10.0	7.0	8.0
7		1.0	1.0	1.6	2.0	2.7
8		1.0	1.0	1.6	2.0	3.0
9		1.0	1.0	1.6	2.0	2.7
10		15.0	15.0	10.0	8.0	12.0
11		4.0	4.0	12.0	2.0	4.0
12		4.0	4.0	12.0	2.0	4.0
13		4.0	4.0	12.0	2.0	4.0
14		13.0	18.0	15.0	13.6	7.7
15		4.0	4.0	12.0	2.0	4.0
16		4.0	4.0	12.0	2.0	4.0
17		4.0	4.0	12.0	2.0	4.0
18		15.0	22.0	20.0	20.0	7.7
19		4.0	8.0	23.0	3.0	12.0
20		6.5	6.5	29.0	3.0	12.0
21		6.5	6.5	29.0	3.0	12.0
22		22.0	44.0	30.0	30.0	7.7
23		6.5	6.5	29.0	3.0	12.0
24		9.0	5.0	35.0	3.0	20.0
25		6.5	6.5	29.0	3.0	12.0
26		13.0	18.6	15.0	13.6	7.7
27		6.5	6.5	29.0	3.0	12.0
28		6.5	6.5	29.0	3.0	4.0
29		6.5	6.5	29.0	3.0	12.0

APPENDIX II - SOIL AND NUTRIENT LOSS CALCULATIONS FOR CHAPTER 3

Soil loss was estimated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The calculations were done using a computerized procedure (the nonpoint calculator) described by Davis and Nebgen (1979). Calculations were performed on a county basis. There are 43 counties* in the Potomac Basin and 78 in the Susquehanna. (Several counties were not included because only a very small fraction of their area was in one of the basins.)

The important factors involved in the analysis were the parameters in the USLE (rainfall factor, soil erodibility factor, slope-length and steepness factors, cover and management factors, and the support practice factor), land use information, and soil phosphorus concentration and the enrichment ratio. To the extent possible, these factors were obtained from the national data base which accompanies the nonpoint calculator. That data base is intended for preliminary screening calculations, so it should be emphasized that the calculations made were not highly refined ones.

Land use information was obtained from the 1967 Conservation Needs Inventory (CNI). That inventory provides nonurban land use in 16 categories and by land capability class. The conservation needs specified by the 1967 CNI were used to estimate the support practice factor, again by land use and land capability class. These data on land use and practice factor are contained in the data base for each county in the United States. Rainfall factors were estimated on a county-by-county basis for both watersheds.

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* Actually these are county portions of subbasins. There is some double counting since some counties are in more than one subbasin.

Soil erodibility factors, slope factors, and cover factors are provided in the data base by land resource area (LRA) (see Austin (1972) for a discussion of LRAs). There are 156 LRAs in the coterminous United States. Soil phosphorus concentration was also estimated by LRA using results presented by McElroy et al. (1976). The LRAs in which the two river basins are located and soil phosphorus concentration in each LRA are given in Table II-1.

There is no easy way to estimate how the enrichment ratio for phosphorus might vary throughout the basins. In the calculations, a uniform value of 2 was assumed for enrichment.

TABLE II-1. LAND RESOURCE AREAS INCLUDED IN STUDY

LRA classification number and name		Average total soil phosphorus concentration (ppm)
101	Ontario-Mohawk Plains	700
126	Central Allegheny Plateau	700
127	East Allegheny Plateau and Mountains	300
128	South Appalachian Ridges and Valleys	300
140	Glaciated Allegheny Plateau and Catskill Mountains	500
147	North Appalachian Ridges and Valleys	300
148	Northern Piedmont	500
149	Northern Coastal Plain	100

APPENDIX III - ENGLISH TO METRIC CONVERSIONS FOR VOLUME I

TABLE III-1. ENGLISH TO METRIC CONVERSION FACTORS

To convert	Into	Multiply by
inches	centimeters	2.540
feet	meters	0.3048
miles	kilometers	1.609
square miles	square kilometers	2.590
acres	hectares	0.4047
pounds	kilograms	0.4536
tons	tons - metric	0.9072
gallons	liters	3.785
10^6 gal/day	cubic meters/day	3.785
pounds/acre	kilograms/hectare	1.121
tons/acre	tons/hectare	2.242
pounds/mile	kilograms/kilometer	0.2819
tons/mile	tons/kilometer	0.5638
°F	°C	(°F-32)0.5556
EI[a]	EI_m	1.735
K[a]	K_m	1.292

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[a] Erosion index (EI) and soil erodibility factor (K) conversion factors from Wischmeier and Smith (1978).